INNOVATION GEARED
BUILDING RESILIENCE

National Building Research Organisation

11th Annual Research Symposium 2021

PROCEEDINGS

Proceedings of

11th Annual Research Symposium - 2021

Innovation Geared Building Resilience

14th & 15th December, 2021
Waters Edge, Battaramulla

organized by

National Building Research Organisation

Institutional Partners

Academic Partner

Proceedings of 11th Annual Research Symposium - 2021

Symposium Theme - "Innovation Geared Building Resilience"

Advisor

Eng. (Dr.) Asiri Karunawardena, Director General, NBRO

Symposium Organizing Committee

- Mr. KC Sugathapala, Director, Human Settlement Planning & Training Division, NBRO
- Mr. KN Bandara, Director, Geotechnical Engineering & Testing Division, NBRO
- Mrs. SK Muthurathne, Director, Building Materials Research & Testing Division, NBRO
- Dr. HAG Jayathissa, Director, Landslide Research & Risk Management Division, NBRO
- Mr. HDS Premasiri, Director, Environmental Studies & Services Division, NBRO
- Ms. KMDNK Kahahengoda, Project Management Division, NBRO

External Review Panel

- Prof. SMA Nanayakkara, Department of Civil Engineering, University of Moratuwa
- Prof. BCL Athapattu, Professor in Environmental Engineering, Open University of Sri Lanka
- Prof. UP Nawagamuwa, Department of Civil Engineering, University of Moratuwa
- Prof. T Hewawasam, Department of Geography, University of Peradeniya
- Prof. NWB Balasooriya, Department of Geography, University of Peradeniya
- Prof. PK Malaviarachchi, Department of Geography, University of Peradeniya
- Prof. SAS Kulathilaka, Department of Civil Engineering, University of Moratuwa
- Prof. Udayangani Kulatunga, Department of Building Economics, University of Moratuwa
- Dr. Pathmakumara Jayasingha, Department of Geography, University of Peradeniya
- Dr. Thusitha Sugathapala, Department of Mechanical Engineering, University of Moratuwa
- Dr. Shaleeni Coorey, Department of Architecture, University of Moratuwa
- Mr. Clerance Perera, Former Consultant, NBRO
- Mrs. SV Dias, Former Director, Environmental Studies & Services Division, NBRO

Design

- Mr. WKC Kumarasiri, Scientist, NBRO
- Mr. PMCJ Paliskara

ISBN 978-624-5936-01-4

Published in Colombo, Sri Lanka,
by National Building Research Organisation,
99/1, Jawatta Road,
Colombo 00500.

Printed in Colombo, Sri Lanka
by Printec Establishment (Pvt) Ltd.,
52/1, Ekwatta Road, Mirihana, Nugegoda.

Foreword

Eng. (Dr.) Asiri Karunawardena
Director General
National Building Research Organisation

The National Building Research Organisation (NBRO) organizes the Annual Research Symposium as a tradition to disseminate the results of NBRO's research and development program and other related studies, with a special focus on providing competitive advantage and innovation to Disaster Risk Reduction activities in Sri Lanka. In 2019, the 10th annual symposium was successfully conducted as a two-day event. Unfortunately, due to the Covid 19 pandemic situation, the annual symposium could not take place as planned in 2020. Understanding the situation, it has been decided to conduct the 11th Annual Research Symposium this year in a hybrid approach (Online+ limited participants) under the broad theme of "Innovation Geared Building Resilience".

As per the tradition, the symposium is arranged with the cooperation of its local and international stakeholder institutions who collaborate in disaster risk reduction endeavors in Sri Lanka. This year's symposium will be focusing more on innovations and smart technologies adopted to build disaster resilience in Sri Lanka. It will provide pathways to incorporate innovational approaches into building disaster resilience, landslide risk reduction, early warning technology, environmental risk reduction and development of reliable building material technologies. Accordingly, the symposium proceedings consist of research papers on the following sub themes;

1. Investing on resilient environment
2. Technological advancements in building research
3. Non-structural measures for landslide risk reduction
4. Application of digital technologies for risk management

We believe, this symposium will attract researchers, disaster management practitioners, policymakers, and eminent experts from local and international institutions and provide an excellent platform to have discussions, exchange ideas, and share experiences.

The communities in the dry zone of Sri Lanka currently suffer from long-term water stress due to lack of reliable safe sources of water as most of their local water sources are depleted due to influence of rainfall variability and pollution of water sources via Agro -chemicals. Rain Water Harvesting is a reliable option to ensure domestic water security in water stressed communities in the dry zone. In order to promote safe techniques for rain water harvesting, NBRO conducted a research study "Sustainable rooftop-based rainwater harvesting systems to overcome domestic water deficit conditions in the Anuradhapura" under the Research and Development program and compiled a manual titled "A Design Manual for Rooftop Rainwater Harvesting Systems for Sri Lanka". This manual will be launched at the Symposium.

With the frequent occurrence of natural hazards, such as; landslides, novel approaches are concerned in order to minimize losses and damages to lives and properties. NBRO developed a mobile application for real time landslide early warnings dissemination, will be launched at the Symposium, through which information could be delivered accurately on time, to vulnerable communities and individuals in landslide prone areas.

Finally, the stakeholder agencies came forward to assist NBRO with financial aid when organizing the symposium and we wish to thank them profusely. Many local and international participants now frequently attend our annual research symposium and we wish to admire their effort and thank them for the support extended. We take this opportunity to thank the Government of Sri Lanka, relevant authorities, our stakeholders, collaborating agencies, universities, and all the well-wishers of NBRO for the encouragement and support extended generously to make our R&D Program and for the grand success of the symposium. Many thanks are also due to the Presenters, Authors, the Editorial Board, and the Organizing Committee of the 11th NBRO Annual Research Symposium 2021.

Table of Content

Keynote Speaker

ENG. MIKE STANNARD

Eng. Mike Stannard is the Keynote specker on Day 01 of the 11th Annual symposium 2021 which is scheduled on 14th December 2021. Mr. Mike's Keynote Speech is on Building Codes for Resilient Built Environment.

Eng. Mike Stannard was a Chief Engineer for the Ministry of Business Innovation and Employment in New Zealand. He has extensive national and international experience in engineering, building regulation, construction, and project, quality and risk management.

Mike provided technical leadership to central government in its response to the leaky building crisis, the weathertightness failure of house framing, described as a "systemic failure" of the building system in New Zealand.

He also took a lead role for the Ministry's technical work relating to the recovery of the 2010/11 Canterbury earthquakes, including responding to Royal Commission recommendations and implementing lessons across New Zealand.

In 2019, the National Building Research Organisation (NBRO) and Construction Industry Development Authority (CIDA) have jointly initiated development of the Building Code (BC) for Sri Lanka. The World Bank supported this endeavor by connecting a group of Sri Lankan practitioners involved in the code development with leading global experts who can share knowledge and experience of the countries. As part of this support, a video lecture was provided by Eng. Mike Stannard, hosted at the Distance Learning Centre of Sri Lanka Institute of Development Administration (SLIDA).

Eng. Mike Stannard has been involved in developing the building code in New Zealand. He also has a broad knowledge of international building regulations, contributing to understanding the different experiences and issues that have arisen in some other countries. In his presentation he proposed several useful options that Sri Lanka could adopt in framing the BC using his broad subject knowledge.

Mike is a Fellow of Engineering New Zealand and a Life Member of the New Zealand Society for Earthquake Engineering, the Structural Engineering Society New Zealand and the New Zealand Geotechnical Society. He has presented at numerous New Zealand and international conferences.

Keynote Speaker

DR. UCHIDA TARO

Dr. Uchida Taro is the Keynote speaker on Day 02 of the 11th Annual symposium 2021 which is scheduled on 15th December 2021. Dr. Taro Keynote Speech is on Climate Change and Sediment Disasters.

Dr. Uchida Taro is Associate professor at Faculty of Life and Environmental Sciences, University of Tsukuba. He obtained his bachelor degree at Kyoto University, Department of Agriculture Faculty of Forestry, and master's degree at Kyoto University Graduate School of Agriculture Faculty of Forest Science. In 2003 he obtained Doctor in Agriculture at Kyoto University. He has more than 18 years of research experience. His major field of works are related to Forest Science, Debris flow, SABO, Hillslope Hydrology, and Sediment disasters.

He is engaging in several Academic societies such as Japanese Geomorphological Union, The Japan Society of Hydrology and Water Resources, The Japanese Forestry Society, and Japan Society of Erosion Control Engineering. He has published more than 50 academic journal, international conference paper, and articles.

He has worked on several research projects such as Understanding of flood conditions in mountain rivers during heavy rainfall for the improvement of prediction accuracy, Education and research on environmental disaster prevention based on the water environment, A method for analysis of sediment dynamics of sediment sheet flow considering the behavior of fine sediments during heavy rain, Proposal of a method for predicting flood and sediment runoff to quantify the risk of disasters increased by climate change.

Dr. Uchida Taro has been a Head and Senior Researcher at National Institute for Land and Infrastructure Management Sabo Planning Division, SABO Department and Public Works Research Institute Erosion and Sediment Control Research Group. Also, he is been Chief Official at Ministry of Land, Infrastructure and Transport Sabo Planning Division, Sabo Department, River Bureau, Researcher at National Institute for Land and Infrastructure Management Research Center for Disaster Risk Management and Japanese Society for the Promotion of Science.

Message

From The Symposium Organizing Committee

National Building Research Organization proudly presenting the 11th Annual Research Symposium 2021 under the theme of “Innovation Geared Building Resilience”. As the national focal point for landslide disaster risk management and resilient building construction, as well as the Research and Development (R&D) institution under the purview of the State Ministry of National Security and Disaster Management has recognized the need for a total management approach to cope with emerging challenges in disaster risk management.

The institution has proactively taken steps to translate effectively the disaster management policies and approaches into concrete programs, strategies, and activities covering a wide range of disaster risk reduction disciplines including landslides, environmental risks, climate vulnerability effects including floods and drought, resilience in development, disaster forecasting systems, design and build approaches for curbing disaster risks, etc.

We were unable to hold the Annual Research Symposium in 2020 due to the COVID 19 pandemic. However, we could manage to conduct the industrial consultation program in 2020 with representative of various government institutions, private companies, academic institutions and non-governmental organizations. Wide range of research areas such as Determination of regional and local rainfall thresholds, Preparation of technical guidelines for building demolition, Utilization of textile waste in manufacturing paving blocks, Coir embedded roofing sheet, Rainfall thresholds for landslide occurrence in Kaluganga basin, Air quality prediction & preparedness system, Transitional shelters for disaster-affected communities, Hydrological functions of small tank eco systems, Training and community awareness building programmes, Landslide mitigation projects, Relocating and resettling project for the people in high risk areas, Providing guidelines as well as proper designs and recommendations for the mass excavations of sites and ground vibration in rock quarries, Developing of real-time air quality monitoring sensors, university student enrolment for NBRO work and newsletters and other new publications has been discussed in this program.

Considering the prevailing scenario, it is planned to hold the 11th Annual Research Symposium as a hybrid event in 2021 (Online and Limited participant). It is a great opportunity for the NBRO scientist and international experts to publish their research work from a wide range of specialization who have worked hard on timely needed research questions. The proceedings and the forum will form a unique platform for knowledge sharing.

Initially, the abstracts have been collected from the authors and vetted by the Symposium Organizing Committee (SOC) to ensure that they are relevant to the year's theme and the organization's scope. Once the abstracts have been approved, the SOC will notify the authors on how to submit their full research papers. The research papers were verified by the Directors of their respective divisions before they were submitted to the SOC. Following Director authentication, the papers were submitted to SOC via the division R&D coordinators. The papers are then sent to a panel of external reviewers with expertise in the appropriate topic areas. The papers will be resent to the authors with the external reviewers' comments to complete the paper for publication as a proceeding at the symposium's inaugural session.

On behalf of NBRO we would like to convey our gratitude towards the external review panelists: Prof. SMA Nanayakkara, (Department of Civil Engineering, University of Moratuwa), Prof. BCL Athapattu, (Professor in Environmental Engineering, Open University of Sri Lanka), Mrs. SV Dias, (Former Director, Environmental Studies & Services Division, NBRO), Mr. Clerance Perera, (Former Consultant, NBRO), Dr. Thusitha Sugathapala, (Department of Mechanical Engineering, University of Moratuwa), Prof. UP Nawagamuwa, (Department of Civil Engineering, University of Moratuwa), Prof. Tilak Hewawasam, (Department of Geography, University of Peradeniya), Prof. NWB Balasooriya, (Department of Geography, University of Peradeniya), Prof. Sanjeewa PK Malaviarachchi, (Department of Geography, University of Peradeniya), Dr. Pathmakumara Jayasingha, (Department of Geography, University of Peradeniya), Prof. SAS Kulathilaka, (Department of Civil Engineering, University of Moratuwa), Prof. Udayangani Kulatunga, (Department of Building Economics, University of Moratuwa) and Dr. Shaleeni Coorey (Department of Architecture, University of Moratuwa) to make the 11th Annual research as a successful event. We hope that this proceeding will inspire governments and other development partners to create their visions of disaster-resilient futures.

Finally, we would to thank the advisor of symposium Eng. (Dr.) Asiri Karunawardena, the Director General of NBRO, the symposium organizing committee, the editorial and, the design committee to their immense support.

National Building Research Organisation

11th Annual Research

Symposium 2021

INNOVATION GEARED
BUILDING RESILIENCE

Technical Session 1

Investing on resilient environment

Availability of Cd, As and Pb in Agricultural Plants Accumulated by Fertilizers due to Variation of Soil pH; A Case Study From Fet Zone Paddy Fields in Sri Lanka

GV Lankathilaka[1], JDSN Siriwardana[1]

[1]Geologist, National Building Research Organisation, Sri Lanka

Abstract

The main source of food for the population of the world is agriculture. And hence, consuming insignificant amount of foods contaminated by heavy metals could lead to higher level of heavy metal accumulation in the human body with the life time. Heavy metals are readily available in fertilizers and some parts of the soil depending on the geological parameters of the terrain. Therefore, understanding of accumulation pattern and mobility of such heavy metals in soil is necessary.

Intermediate type rice variety was chosen for the present research study and 13 plots were arranged as a function of TSP (Triple Super Phosphate - which is generally using as fertilizer by farmers of Sri Lanka) fertilizer to soil ratio and as a function of pH change. After 85 days of seeding, harvest was dried, grinded and digested before the analysis using Inductively Coupled Plasma Mass Spectroscopy (ICP-MS) technology.

Selected heavy metals of Cadmium (Cd), Lead (Pb) and Arsenic (As) were shown higher accumulation levels in the biomass compared to the availability of heavy metals in the soil. Due to repeated fertilizer usage, paddy soil show higher levels of heavy metals which was 20% of the total biomass. The study revealed that using fertilizers with non-organic agents, level of soil pH has risen and mobility of heavy metals were increased. To overcome this problem the pH of soil need to be maintain within safe limits.

Key words: Agriculture, Heavy Metals, Soil pH, Concentration, Human Body, Paddy Fields

1. Introduction

Among hundreds of elements that are found in the earth crust, most of the heavy metals are known as toxic compounds to humans. Cadmium (Cd), Arsenic (As) and Lead (Pb) are example to such toxic elements (Chandrajith et al., 2008). These metals are not very common in the earth crust. Metamorphic sedimentary and igneous processes create cyclic manner that these chemicals can weathered and deposited easily. Weathering of such rocks releases all of its contents into soil and easily allows them to contaminate natural water bodies. Through these processes toxic and non-toxic compounds enter into the human body (Ali et al., 2019). These elements entering into human body in various ways. Such as dissolved in food and water.

However, in addition to these two, also from breathing, particles of metals can get into human bodies such as smoking. Average dietary intake of Cd for nonsmokers living in uncontaminated areas is between 10 and 25 μg Cd per day (Roberts, 2014) and hence the tobacco smokers are exposed to 1.7 μg Cd per cigarette and about 10% is absorbed by the body when smoked. Rice is considered as one of the most important cereal crop in the country although Sri Lanka is centralized by agricultural activities since the period of ancestors. And hence rice is considered as the staple food for more than half of the world's population (Jiang et al., 2013) from the recent past.

Most heavy metals such as Cd and As can easily be accumulated by plants and crops through their root systems and are present in all foods (Alam et al., 2003) due to adding excessive fertilizers for unconscionable yield in the crops including the rice fields by farmers. Usually, older plants or plant parts contain more Cd concentration than the younger ones (Louekari et al., 2003). One another aspect is these fertilizers contaminated with ground water and concentrated with these toxic compounds. After several years, exposing to such contaminated ground water, health problems are arising eventually in the human body.

The main known effect of metals such as As and Cd are heavy metals to human health is kidney disease (Roberts, 2014). Well known fertilizers with high heavy metal content is Triple Super Phosphate (TSP) which is applied to the vegetable and rice fields twice a year in the country. Therefore TSP can be collected easily from local shops in Sri Lanka for the experiments. Some alternatives have been introduced by the government to reduce the usage of all fertilizers within the fields. But no any legal limitations or actions has taken place by the government yet to restrict the chemical fertilizers by the farmers.

Phosphate rocks are the major resource of producing TSP. It is generally accepted that the pH of a soil is one of the most important factors controlling the absorption of heavy metals to biological substances like plants (Amini et al., 2005). Since only small portion of absorbed heavy metal is removed by the crops and hence the repeating activities of the fertilizing can lead to higher levels of accumulations within the biomass.

Phosphate fertilizers have a plant growth enhancing effect, increasing the plant's biomass, which can also result in a dilution effect on the Cd within the plant. It has been reported that application of zeolite can effectively suppress the Cd uptake by rice and wheat than calcium carbonate or manganese oxide application (Wijayawardhana at el., 2016). Rice researchers have introduced an improved rice varieties that having the reduced amount of in heavy metal uptake. But there are various types of traditional and intermediate rice varieties that are usually using by farmers but most farmers are not familiar with new rice varieties because of the less knowledge about handling about the crop. However every plant showing some amount of heavy metal absorption while most traditional varieties presents with higher uptake conditions.

2. Study area

Paddy fields where the soil samples were collected belongs to Godagandeniya - 283 Grama Niladhari Division of Yatinuwara Divisional Secretariat in Kandy District of Central Province of Sri Lanka. Area can be accessed travelling through Peradeniya - Gampola main road (A5) and it is located in between the 5 & 6 km post of this main road which is the major access to Panideniya area.

The study area is located in the wet zone of the central highlands of Sri Lanka which having the unique landscape and rainfall patterns. The average annual rainfall of the area is 2,132 mm. Average annual temperature of the area is about 24.6 ^{0}C whereas the temperature may drops in some periods with the increase of elevation in mountainous terrains. The selected study terrain is consists with nearly flat area with paddy fields. The bedrock is not often exposed but thin colluvium cover and marshy lands are dominant within area with the presence of various sizes of boulders. Bedrock exposures in some areas having Garnet Biotite Gneiss exposures of bedrock are covering nearly 5% of the area. General slope angle of the area is 5-10 degrees. Moderate to high weathering conditions of the soil and the Garnet Biotite Gneiss bed rock present in the study area is in highly weathered condition.

GPS coordinates of the study area is X = 179457.38 and Y = 228453 and the elevation from the mean sea level is 486.56 m. Study area lies on the 54 sheet of 1:50,000 topographic map published by the surveying department Sri Lanka and on the map no. 14 of 1:100,000 scale Geology Map published by the Geological Survey and Mines Bureau, Sri Lanka. According to the 1:50,000 Landslide Hazard Zonation Map published by National Building Research Organisation (NBRO) the affected area lies on landslides are not likely to occur category.

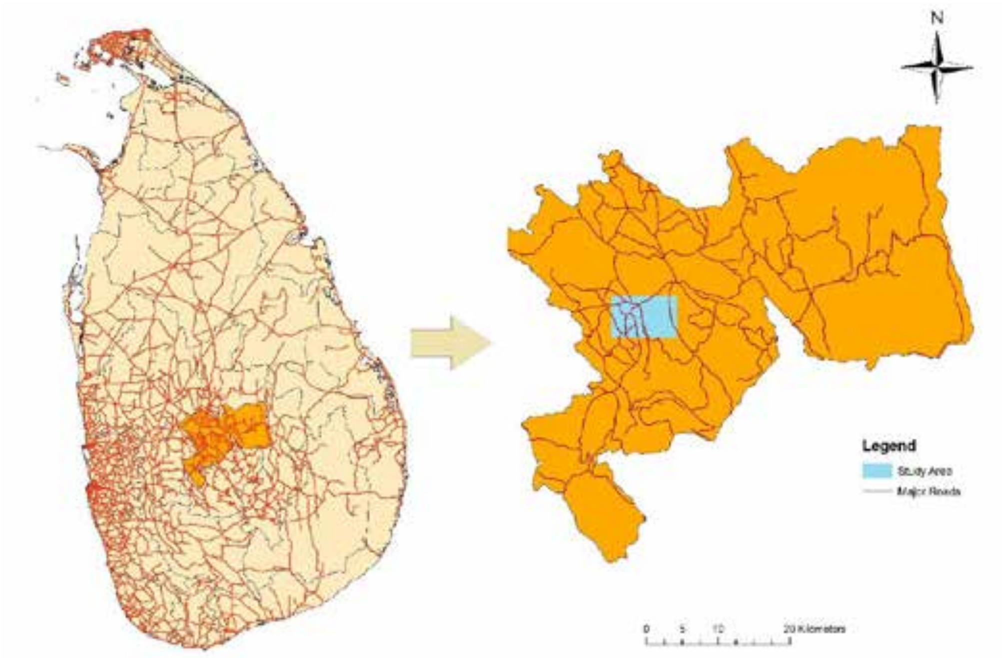


Figure 01: Location map of the study area

3. Methodology

Soil samples were collected according to the volume of the each plot. The soil samples were collected by removing top layer organic materials down to 6 inches. Soil was under submerged conditions when it was collected and transported to laboratory.

The chemical parameters were measured at the Geochemistry Laboratory of Department of Geology, University of Peradeniya. The pH of all soil samples were measured by using HANNA HI 8314 pH meter. pH meter was calibrated by using 4.01, 7.00 and 10.01 buffer solutions before measurements. Solution of each soil sample was prepared and the pH was measured regularly. Inductively Coupled Plasma Mass Spectroscopy (ICP-MS) method was used to analyze the concentrations of trace elements in the soil and TSP fertilizer samples.

Twelve plots were arranged according to TSP and pH variations. Five variations were prepared to understand the behavior of the samples under the above two parameters. TSP was added from recommended rate to the higher levels. TSP to soil ratio was changed from 60:1 to 12:1 on dry weight basis. pH value was controlled within 4.5 to 10.5 limits. Under this parameters, two plots were prepared as control plots. Any other heavy metal contaminated source were not applied to the test sample.

Five plots were arranged with variation of pH (4.5 to 10.5) with same TSP amount (50g) and another four plots were set with variation of TSP content for same pH of 4.5. Secondly another 4 plots were arranged with variation of both parameters. Used rice variety for the test named ***"Nadeera"*** (harvesting time is 90 days) was used to identify the uptake amount to the biomass. Plots were controlled in submerged conditions in throughout the growth period. No other fertilizers added except TSP at all the time.

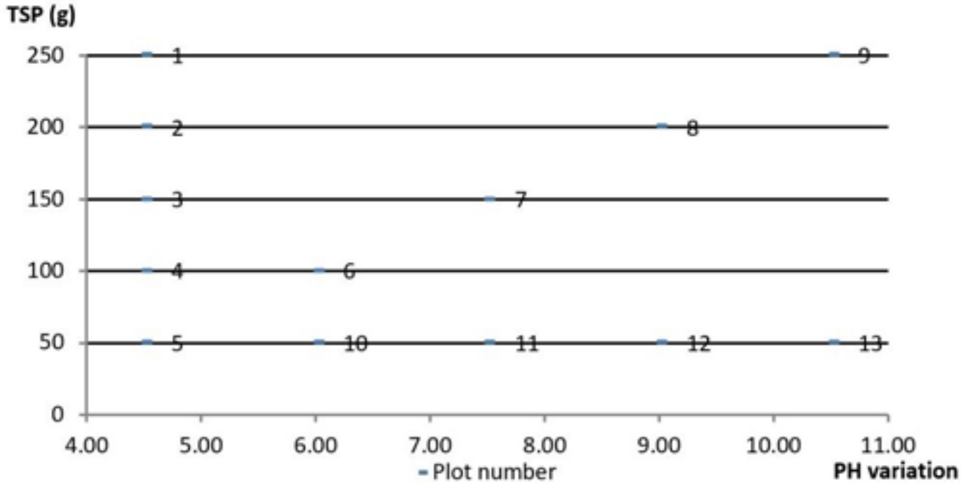


Figure 02: Arrangement of plots with variation of pH and TSP

Soil amendments were used to reduce and increase the soil pH. Original pH varies between 6.9 - 7.6 in the collected samples. Soil buffering was unavoidable facts so the adding of soil amendments were repeated in some cases to get the closes target pH value. Liming ($CaCO_3$) was done to decrease the pH of plots. $CaCO_3$ added as fractions and observed fluctuation of the pH and Soil buffering. Similarly Sulphur (S) added to decrease the pH and observed for variations under submerge conditions.

Heavy metal concentration level in the soil and TSP were also measured by using ICP-MS - "ICapQ ICP-MS thermos fisher of Bremen Germany" and the detection limit of considered heavy metals is 0.0027 ppb (µg/L). Therefore. Finally, after growing the plants for 85 days, biomass of rice plants were tested to measure heavy metal levels using ICP-MS technology.

TSP and soil samples digested using the same procedure before detection test. First, samples were heated in the oven for 48 hours until it has completely dried. Then the samples were ground by hand to make fine powder. Secondly, 0.2 g of sample is weighed in the reaction vessel. 6 ml of nitric acid and 2 ml of hydrochloric acid then added to each vessel.

Finally 1 ml of hydrogen peroxide was added to the sample. The vessel is allowed to react for approximately 30 minute prior to sealing it. Vessels were kept in the rotor and subjected to microwave heat. Then the vessels were heated up to 180°C over 15 minutes and then held at 180°C for at least 10 minutes. Then the samples were taken out when the inside temperature of microwave oven drops below 40°C. Plant samples were dried in the sunlight for nearly 48 hours before placed in oven reduce the biomass and weight. After that the dried plants were kept in the oven for nearly 48 hours at 50^0C temperature. Plant samples were then ground by hand until fully pulverized. And then same procedure was applied as in soil and TSP. All the samples were micro filtered before analysis in ICP-MS.

4. Soil pH and TSP variations

Original soil pH of samples were varied in a large scale. And hence controlling of pH and adding lime rates were more confusing factors within this experiment. According to the above plot numbering, 13, 9 plots need 130g of $CaCO_3$ to increase pH from three units according to the SMP buffer method (Mclean et al., 1977).

After adding 100 grams of $CaCO_3$ and slowly mixing the lime, the value of pH were increased up to 10.5. After that the soil sample was well mixed and submerged. The sample was subjected to recheck the pH value after 48 hours. Value of the pH was decreased up to 0.8 at that time

This method was repeated to the plot numbers 13 and 9 till the 10.5 of pH does not changed meanwhile. The method was repeated for the plot numbers 8 and 10 according to the finding of (Mclean et al.,1977). The experiment has figure out 70 - 80 grams of lime needed to increase the pH from 1.5 units. Lime or Sulphur does not added to 7 and 11 plots, from the rest nine plots, author choose the closed two plots with 7.5 pH.

Decreasing of pH was done by using Sulphur as soil amendment. Because there are no any standard methods to acidify the soil, as the sample has analyzed the quantity of Sulphur needed to decrease the value of pH of one unit for 100g of soil at the laboratory conditions. According to that 50g of Sulphur needed to decrease the value of pH by 2 units and 30g for one unit. The number of 1, 2, 3, 4 and 5 plots were mixed by using 35g of Sulphur and observed till the value of pH stables at 4.5.

5. Results and Discussion

Concentration of heavy metals in the biomasses depends on the natural availabilities of the soil. According to the results, Arsenic (As) and lead (Pb) concentrations present in the normal paddy fields were recorded in amount rather than the normal soil present in other areas except the paddy fields. This scenario was mainly due to the repeated application of the adding excessive fertilizers in every harvesting season. Results show nearly 20% of heavy metals added though fertilizers were accumulated in paddy soil and rest are eroded through water bodies and removing by the crops. Therefore, availability of toxic heavy metals in natural paddy soil has increased due to modern harvesting technologies. Due to less organic material availability and low pH conditions, accumulation of heavy metal concentration in the biomass has increased. Further it was identified that fertilizer level in soil having direct relationship with the soil pH. Fertilizers are mainly produced from phosphate or nitrate based sources and therefore with the usage of such fertilizers the soil pH tend to decrease time to time.

However absorption of heavy metals to the biomass not showing any direct relationship with applied fertilizer content but exhibits a clear relationship with pH. If the pH conditions were lesser than 6, it may be showing rapid mobility and absorption in selected heavy metals. But if the absorption is in the range of 8.00 - 9.00 the mobility of heavy metals are less in the biomass. Therefore according to the present study, pH conditions between 7.5 to 9.0 can be demarcated as safe pH level for agriculture and pH levels more than 9 is not safe even the lower acidic level is present in the soil. It may happen due to the availability of liming agent, probably $CaCO_3$ in the heavy metals as impurities. Presence of heavy metals in the biomass of agricultural agents and other sources including paddy soil and TSP shown in table 01. And the Heavy metal concentration with variation of soil pH is shown in the figure 03.

Table 01: Heavy metal concentration in each plot and resources

	As	Cd	Pb	Total heavy metal concentrate
Plot 1	4.42	2.92	12.11	19.45
Plot 2	5.81	2.08	10.63	18.52
Plot 3	3.43	2.39	3.88	9.70
Plot 4	1.00	60.09	1.95	63.04
Plot 5	0.55	2.91	2.67	6.13
Plot 6	1.68	1.98	2.09	5.75
Plot 7	3.82	1.92	3.59	9.33
Plot 8	1.35	1.38	2.29	5.02
Plot 9	2.08	3.32	2.32	7.72
Plot 10	0.88	2.3	1.70	4.88
Plot 11	1.14	2.44	2.44	6.02
Plot 12	1.86	2.04	2.12	6.02
Plot 13	2.66	1.5	2.18	6.34
Control plot	1.55	2.09	1.98	5.62
Control experiment	0.24	1.94	1.16	3.34
Soil	13.78	2.98	81.85	98.61
TSP	76.14	5.99	285.92	368.05
Water	0.07	0	0.29	0.36

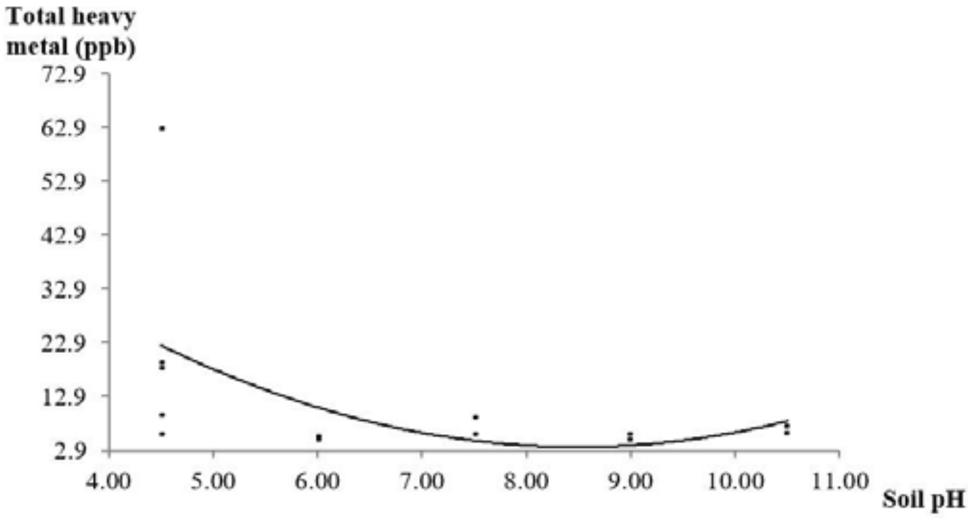


Figure 03: Heavy metal concentration with variation of soil pH

6. Conclusions and Recommendations

The study reveals that higher accumulation in the heavy metals in paddy fields occurs when the value of soil pH value of soil is < 6. Hence the accumulation levels can be demarcated as safe, when the soil pH range is in between 8 to 9. However, when the pH of soil exceed 9, it may increase the availability of heavy metals both in soil and the biomasses due to presence of heavy metal impurities in liming agent. Therefore, soil pH in agriculture need to maintain properly after every harvesting period to avoid heavy metal mobility. Availability or accumulation of heavy metals in soil is uncontrollable and therefore, monitoring and altering pH level to desired level could be least and best option for the farmers to reduce the heavy metal concentration in both paddy fields and crops.

7. Acknowledgement

Assistance by the Department of Geology, University of Peradeniya and Nuwara Eliya District office of Landslide Research and Risk Management Division of National Building Research Organization are thankfully acknowledged.

8. References

1. Ali, H., Khan, E., Ilahi, I. (2019) Environmental Chemistry and Ecotoxicology of Hazardous Heavy Metals: Environmental Persistence, Toxicity, and Bioaccumulation in Hindawi Journal of Chemistry.
2. Alam, M.G.M., Snow, E.T. and Tanaka, A. (2003) Arsenic and heavy metal contamination of vegetables grown in Samta village, Bangladesh. The Science of the Total Environment. 308; 83–96.
3. Amini, M., Khademi, H., Afyuni, M., Abbaspour, K.C. (2005) Variability of available cadmium in relation to soil properties and land use in an arid region in central Iran. Water, Air, & Soil

Pollution. 162; 205-218.

4. Chandrajith, R., Koralegedara, N., Ranawana, K.B., Tobschall, H.J, and Dissanayake, C.B. (2008) Major and trace elements in plants and soils in horton plains national park, Sri Lanka: an approach to explain forest die back. Environmental Geology. 57; 17–28.
5. Jiang, S.H., Zhou, H., Lin, D.Z., Dong, Y.J., Ye, S.H. and Zhang, X.M. (2013) Identification and gene mapping of a thermo-sensitive leaf-color mutant at seedling stage in rice. Chinese Journal of Rice Science. 27; 359 - 364.
6. Roberts, T.L. (2014) Cadmium and Phosphorous Fertilizers: The Issues and the Science. Procedia Engineering. 83; 52 - 59.
7. Wijayawardhana, D., Weerasinghe, A. and Herath, V. (2016) Effect of Organic Matter Application on Growth of Rice (Oryza sativa L.) in Cadmium Contaminated Sand. International Journal of Chemical, Environmental & Biological Sciences. 4; 2320-4087.

Implication of "Red and Yellow" Hazard Zonation Principle Map for Vulnerability Assessment of Residential Allotments on a Waste Dumping Site: A Case Study from Bogahawaththa, Akmeemana, Sri Lanka.

EMJCB Edirisuriya[1], MAK Kumari[1], WMSK Weeranayake[1]

[1]Scientist, National Building Research Organisation, Sri Lanka

Abstract

There has been a competition for residential allotments around major urbanizations of Sri Lanka, during the last two-three decades. Rapid population growth, limited land availability, and also avocation availabilities around such urban areas have intensified this competition for land, ultimately directing towards building abodes on preceding waste dumping sites of urban areas. Such an inhabited settlement on a former waste dumping site has been experiencing cutting failures and instability issues in Bogahawaththa Grama Niladhari Division in Akmeemana Divisional Secretariat Division of Galle district since 1994. With the seasonal and perennial thundershowers, especially during the SW monsoonal period, series of cutting failures and instability issues are quite common in this area threatening the lives of inmates and their properties. Though there are such instabilities because of its subsurface settlements, inmates are constructing their dwellings illegally on the same land adding extra load to the existing load. Therefore, this study is focused on assessing the vulnerability of this landfill failure to minimize the potential threat and make a platform for suitable structural mitigations. The study area is 0.83 hectares consisting of 38 abodes with permanent and temporary subordinate structures. Parameters such as soil type, soil thickness, cut height, and distance between cut and each house were obtained for this vulnerability assessment. Based on the parameters measured, an overburden map was prepared using ArcGIS and a hazard zonation map was prepared to determine the risk level for the community by using the "red and yellow" hazard zonation map for slope failures method. According to field investigations, three overburden layers were identified as a waste layer, fill soil layer and residual soil layer. Out of the total surface

area, 69.9% is covered by residual soil, 27.4% is covered by waste, and 2.7% is covered by filled soil. One residence was completely established on the waste layer, 23 residences were built on the residual soil layer and 14 residences were built on the both residual and waste layers. The results of this study explicate the importance of vulnerability assessment for the utilization of structural mitigations to reduce the risk.

Keywords: ***Landfill Failure; Overburden Map; Red Zone; Yellow Zone; Structural Mitigations***

1. Introcuction

Landfills have consistently, in the past as well as today, been the primary method for waste disposal. Solid waste, especially Municipal Solid Waste (MSW), is a growing problem in urban areas of Sri Lanka and this problem is aggravated due to the absence of proper solid waste management systems in the country. At present, in many instances, solid waste is collected in a mixed state and is dumped in environmentally very sensitive areas, causing numerous environmental impacts. Rapid population growth in major urban centers in many developing countries has created landfills associating slopes, which are frequently surrounded by illegal low-income residential settlements developed too closed to the landfills. These landfills are facing high risks of catastrophic failure with potentially large numbers of fatalities. On April 14, 2017, mega-landfill failures have occurred in Meethotamulla, the largest open dumpsite in Colombo, Sri Lanka that killed more than 32 people and injured several others (Munwar et al., 2018). Approximately 72,342 m^3 of waste was moved during the failure (NBRO, 2017), making it the second major solid waste landslide of the year. This calls for more landfill failure investigations to prevent loss of human lives and major environmental consequences.

Landfill failure hazard is a function of waste material geotechnical properties, while the consequence is a function of waste material rheological parameters. The range of geotechnical and rheological characteristics of the waste materials are provided by the analyses of documented landfill and dumpsite failures.

Several landfill failure incidences that occurred during the past few years are extraordinary compared to the last few decades with the intensive precipitation of monsoonal rain. Damage associated with those landfill failures has increased due to the growth of human resettlements into the risk-associated landfill area with improper ground modifications and toe excavations, construction activities, and bad land-use practices. An important contributory factor leading to the failures was the complete absence of compaction of the waste or absence of consistent and uniform compaction. Another possible contributory factor may be the plastic pockets filled with water which affect the shear strength of the landfill also makes permeability for vertical flow of water through the waste very much less than for horizontal flow.

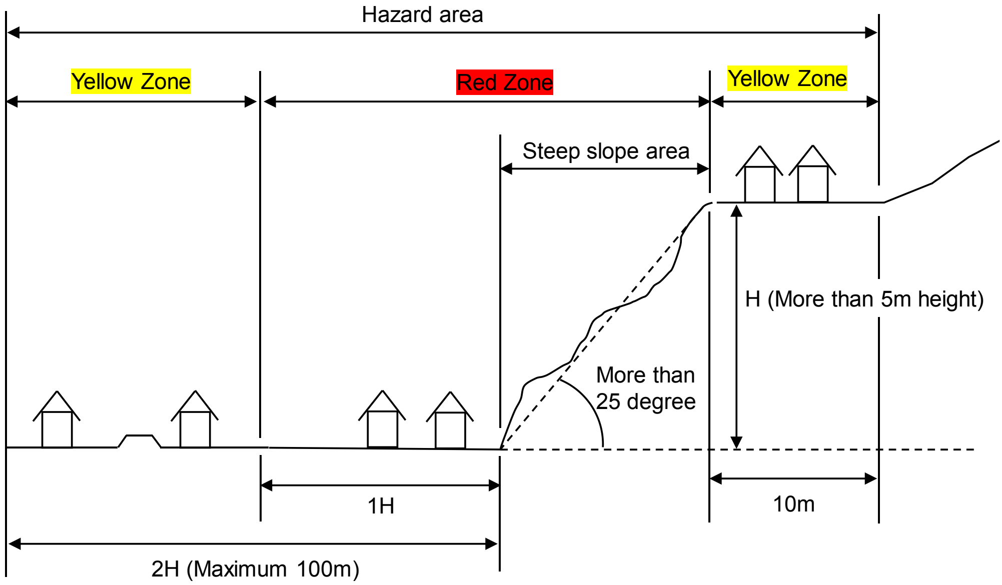


Figure 01: Illustration of yellow zone and red zone for slope failure

Over the last 25 years, the Bogahawaththa landfill has been hit by several exceptional seasonal monsoon rainfall events and has undergone sudden failure resulting in the inundation of houses, causing damages to the buildings, infrastructures and reporting a child's death. Dumping at the Bogahawaththa site has been commenced before 1990 on the side of a hill without any attempt either to compact or cover it to avoid the infiltration of rainwater, which led to building up the pore pressure within the solid waste mass. Illegal human resettlements were set up after the termination of waste dumping and a few residential allotments were established at the early stage of resettlement. During the last decade, relocation was expeditiously increased due to rapid population growth, resulting in ground modifications and constructions associated with the landfill.

The level of the risk is generally defined as the intersection of hazard with the value of elements at risk by the way of their vulnerability (Croizer and Glade, 2006; Alexander, 2002). Characteristics are determined by physical, social, economic, and environmental factors or processes which increase the susceptibility of an individual, a community, assets, or systems to the impacts of hazards, and it is called vulnerability (UNISDR Terminology, 2017).

"Landslide Hazard Yellow Zone" is defined as the area which is vulnerable to landslide and it is called a "Yellow Zone" for brevity. It means that the resistance capacity of normal buildings in the Yellow Zone is larger than the force acting on buildings due to debris and earth. "Landslide Hazard Red Zone" is defined as the area where serious damages are probable to buildings and humans due to landslides and it is called a "Red Zone" for brevity. It means that the force acting on buildings due to debris and earth in Red Zone is larger than the resistance capacity of normal buildings. Therefore, normal buildings in Red Zone would be completely destroyed by debris and earth (Figure 01).

The preliminary studies conducted by National Building Research Organisation (NBRO), Galle District office revealed that there were no proper ways and means for disposing of the waste at the Bogahawaththa landfill. The solid waste of Bogahawaththa landfill comprises high amounts of decomposed biomedical waste of organic and plastics indicating the lower density profile of the waste. Further, there were no proper compaction and working methodologies. The goal of this study, therefore, is to introduce the framework to evaluate the risk of landfill slope failure. This study is also focused to assess the vulnerability of this landfill failure to minimize the potential threat and make a platform for suitable structural mitigations.

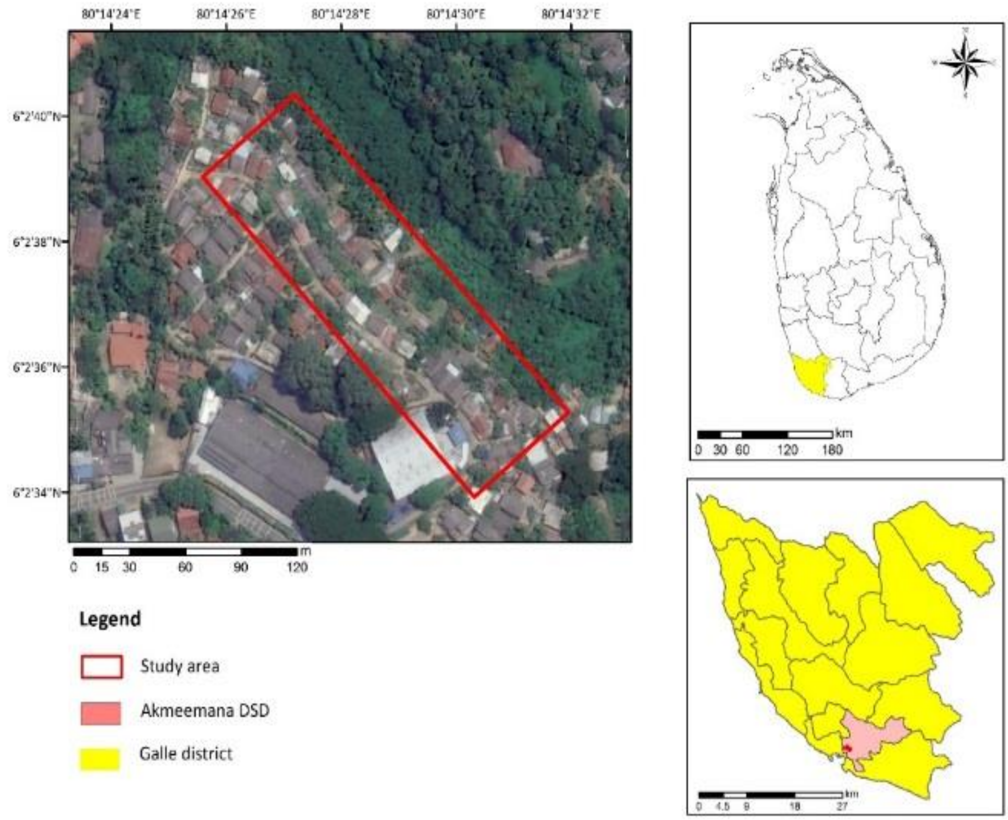


Figure 02: Study area of Bogahawaththa landfill site

2. Study Area

The studied landfill area belongs to Bogahawaththa Grama Niladhari Division of Akmeemana Divisional Secretariat Division in Galle district of Southern province of Sri Lanka. The investigated area is shown in Figure 02 and it lies between latitude from 6.044242 to 6.043029 and longitude from 80.240730^{0} to 80.242035^{0}. The Area is located 13m above the mean sea level.

The study area is 0.83 hectares consisting of 38 abodes with 29 permanent and 9 temporary subordinate structures. The area of the failure is cut slope around 200 m in length and 28 m in width. The height of the cut slope is between 4 m to 12.5 m. The average annual rainfall of the area is about 2500 mm - 3000 mm as this area belongs to the wet zone of the island. As the result of the northwest monsoon, several catastrophic cut slope failures occurred on 13th May 2021 where 150 mm of daily rainfall was recorded. The geology of the area consists of Charnockitic gneiss.

Figure 03: Photographs showing cut slope failures in the Bogahawaththa landfill

3. Methodology

Preliminary investigations on 38 houses located in the considered area, were carried out on 14th and 15th of May 2021. Dimensional of the cut slope such as height, length, and distance to each house from the edge of the cut slope, soil layer thickness, and cut slope angle was measured using the distance meter and measuring tape with the accuracy of 0.1m and their corresponding GPS coordinates in WGS-84 were obtained.

Soil types were determined on the visual basis as observed in the field and soil layer thickness in the area was obtained by the cross-sections drawn for each critical location (Figure 03). All the collected data were arranged into a systematic database. Based on the collected data overburden map was created using ArcGIS software.

The Setting of "Yellow Zone" and "Red Zone" for slope failure are in accordance with the following steps,

1. Selection of Target Area and Preparation Google maps

The target area selected for slope failure should be a steep slope having a gradient of more than 25 degrees and a height (H = h1, h2, h3…) of 5 m. Google maps were prepared as the base maps using Google earth to indicate the lower and upper edge of the cut slope, home locations, and overburden layers (Figure 04).

2. Setting of "Yellow Zone" and "Red Zone"

The red zone was established with a distance of H=h1, h2, h3… from the line of the lower edge and the yellow zone was established with a 2H distance from the line of the lower edge of the cut slope towards the down slopes. The yellow zone for upper slopes was established at a 10m distance from the line of the upper edge (Figure 04).

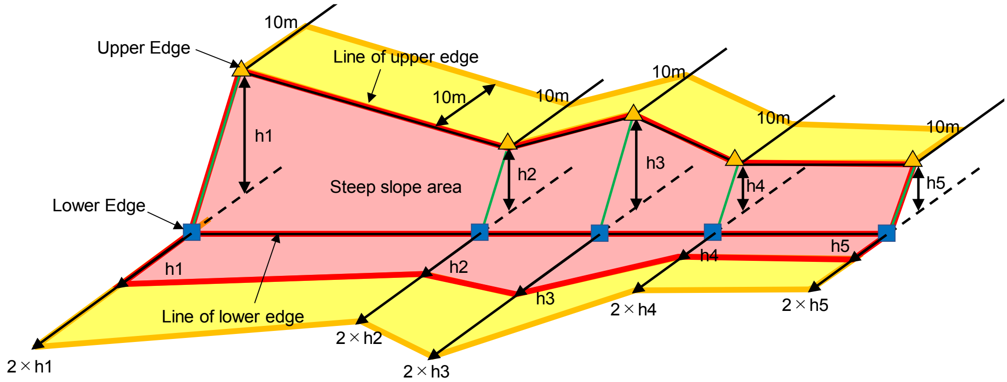


Figure 04: Representation of yellow zone and red zone for slope failure

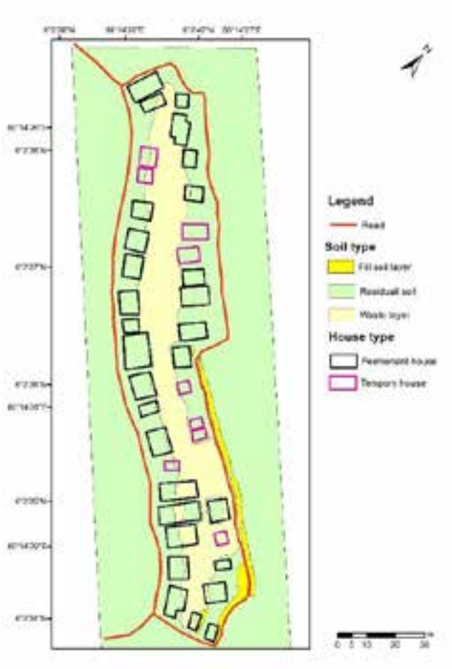


Figure 05: Overburden map of the area

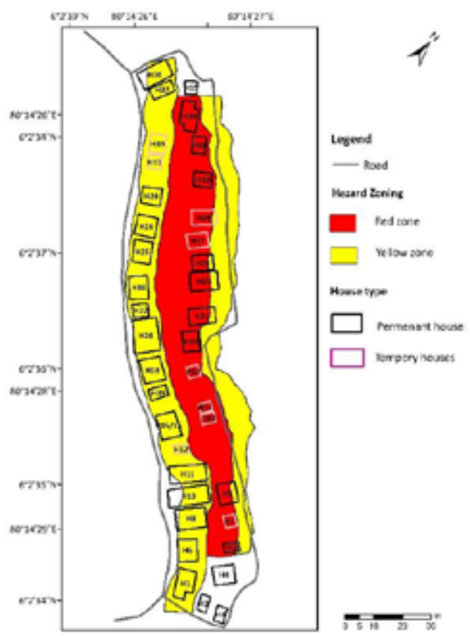


Figure 06: Hazard zonation map

4. Results and Discussion

In this paper, we dealt with regional-scale mapping to estimate the vulnerability and the risk level for the infrastructures and the community. The probability distribution of the surface overburden layers at a regional scale indicates three major overburdens layers over the hill slope as a waste layer, residual soil layer, and filled soil layer. Calculations show that the total surface area of the incidents that occurred is 8,336.34 m^2. Out of the total surface area, 69.88% is covered by residual soil, 27.38% is covered by waste, and 2.73% is covered by filled soil (Figure 05). Field observations, cross-sections, and photographs of the soil profile indicate the thickness of the waste layer is varying from 0 to 9 m. Out of the total houses, 29 are permanent abodes built of cement and bricks and 9 are temporary abodes built of timber panels. Therefore, temporary structures are most vulnerable to serious damages meaning that low resistance capacity concerning permanent structures. Only one residence was completely established on the waste layer and as the majority, 23 of residences were built on the residual soil layer and 14 of residences were built partially on the residual layer as well as waste layers.

Based on the risk assessment carried out during the fieldwork-based on visual observations, associating regional cut slope failures, the risk level for each residential allotment was determined in three different risk levels as low risk, medium risk, and high risk. Out of 38 abodes, 9 residences are at high risk, 10 residences are at medium risk, and 19 residences are at low risk (Table 01 and 02). Hence, a proper scientific method must describe and assess the vulnerability and risk for each allotment, "Red and yellow zone hazard zonation map method for cut slope failure" was used for accurate output. Red and yellow zone hazard zonation map indicates 15 abodes are located in the red zone meaning that structure can be seriously damaged due to the colliding debris and earth and 19 abodes are located in the yellow zone meaning that no vulnerability for serious structural damages, since, the resistance capacity of buildings is larger than the force acting on buildings due to debris and earth.

But temporary abodes are expected to be exposed to serious damage at a landfill failure, even though they are located in the red zone or yellow zone (Figure 06, Table 01 and Tabel 02).

Table 01: Risk level (in letters) and hazard zonation (in colours) for each house (green –low risk, yellow – medium risk and red – high risk)

House number	Risk level and hazard zone	House number	Risk level and hazard zone	House number	Risk level and hazard zone
H1	LR	H14	HR	H27	MR
H2	LR	H15/16	LR	H28	MR
H3	LR			H29	MR
H4	LR	H17	HR	H30	HR
H5	LR	H18	LR	H31	HR
H6	LR	H19	HR	H32	HR
H7	MR	H20	LR	H33	HR
H8	MR	H21	MR	H34	HR
H9	LR	H22	LR	H35	LR
H10	LR	H23	MR	H36	LR
H11	LR	H24	MR	H37	MR
H12	MR	H25	LR	H38	LR
H13	HR	H26	LR	H39	LR

Table 02: Number of houses in a certain hazard zone with respect to the risk level Risk level

		Risk level		
		Low risk	Medium risk	High Risk
Hazard zonation	Red zone	02	06	07
	Yellow zone	13	04	02
	none	04	-	-

5. Conclusion

Combining both hazard zonation mapping and risk assessment can lead to a more informative assessment of the threat to the community. Scientific literature offers various methods to assess risk and economic losses due to landslide events; both of these features represent the central topic when decision-makers are called to act toward prevention, and thus an in-depth analysis is needed to obtain the best results with the least effort. The results of this study explicate the importance of vulnerability assessment for the utilization of structural mitigations to reduce the risk

6. Acknowledgement

The authors would like to acknowledge the support given by Bogahawaththa Grama Niladhari and villagers at the Bogahawaththa area for their enormous support given during the field visit.

7. References

1. Alexander, D., Vulnerably to Landslides, (2002). Landslide Hazard and Risk, John Wiley & Sons, Jan 4, 2006, (pp75).
2. Basha, B.M., Ravitheja, K.V.N.S., (2018). Meethotamulla Landfill Failure Analysis: A Probabilistic Approach. Krishna, A. Murali; Dey, Arindam;
3. Sreedeep, S (2018). [Developments in Geotechnical Engineering] Geotechnics for Natural and Engineered Sustainable Technologies, Meethotamulla Landfill Failure Analysis: A Probabilistic Approach. , 10.1007/978-981-10-7721-0(Chapter 20), 341–351.
4. Brejda, J.J., Thomas, B., Jeffrey, L.S., Douglas L., Deborah L., Thanh H.D., (2000). Distribution and Variability of Surface Soil Properties at a Regional Scale. Soil Science Society of American Journal-2000, (pp974)
5. Edi, H.T., Stark, T.D., Evans, W.D., Sherry, P.E. (2000). Municipal Solid Waste Slope Failure. I: Waste And Foundation Soil Properties. Journal of geotechnical and environmental engineering-2000, (pp397)
6. Geoffrey, B., (2008). Slope failures in municipal solid waste dumps and landfills. Waste Management and Research-2008, (pp448)
7. Glade. T., Malcolm, G.A., Crozier, J.M., Landslide Hazard and Risk, John Wiley & Sons, Jan 4, 2006, (pp75)
8. Hemasinghe, H.H., Jayaprakash, R., Nishikawa, T., Ito, M., Yang, p., Jayatissa, H.A.G. (2019). Application of Yellow Zone and Red Zone Concept to Identify Debris Flow Prone Sites in Sri Lanka- A Case Study of the 2017 Debris Flow at Morawakkanda. NBRO 10th Annual Research Symposium-2019, (PP313).
9. Hettiarachchi, J.M., Siriwardhana, J.D.S.N., Lakmini, K.G.S., Wijekoon, H.M.B.B. (2019). Influence of Rainfall Pattern Over Combined Causative Factor for a Landslide-A Case Study Based on Rainfall Triggered Landslide at New -Valley in Nuwara-Elliya District, Sri Lanka. NBRO 10th Annual Research Symposium-2019, (PP185).
10. Jahanfar, M.A, (2014). Landfill Slope Stability Risk Assessment.
11. Manual for Site-Specific Landslide Hazard Zoning. Project for Capacity Strengthening on Development of Non-Structural Measures for Landslide Risk Reduction in Sri Lanka. National Building Research Organization and Japan International Cooperation Agency (JICA)-(2020)

Disaster Event Analyses in Mid of May 2021; A Case Study from Galle District

WMK Weeranayake[1], MAK Kumari[1], EMJCB Edirisuriya[1], WGK Madushan[1]

[1]Scientist, National Building Research Organisation, Sri Lanka

Abstract

The increasing trend of population growth in Sri Lanka has resulted in rising land demands and construction. Hence, it adversely affects the stability of natural slopes caused by slope modifications. Galle has been declared as one of the landslide-prone Districts by the National Building Research Organisation (NBRO). Recent modifications to natural slopes cause cut-slope failures, which have become a dominant disaster surpassing landslide. Therefore, in every heavy rainfall event, a considerable number of cut-slope failure incidents are being recorded while disturbing numerous ways to the habitual life of people in the area. The primary focus of this case study was analysing the disaster situations in affected Divisional Secretariats of Galle District, in heavy rainfall events in mid of May 2021. Field investigations were carried out in the affected areas and locations were categorized according to the risk levels and type of failures. Rainfall data were analysed to study the relationship between hourly rainfall and cumulative rainfall of the respective catchment. Among the failures which occurred within the subjected disaster period, 90% were cut-slope failures, 7% were slope failures and 3% were potential cut-slope failures. As for the risk level, 80% were medium risk and 20% were high-risk locations. Lack of awareness about mitigation methods, improper drainage systems, and construction practices can be considered as primary causative factors for the occurred failures. Implementation and practicing of proper building construction guidelines among the community and community-based awareness are important to reduce the risks. Further, the present study revealed that existing threshold values of rainfall are no longer applicable for cut-slope failures and, almost all the failures have occurred before 75mm of cumulative rainfall per day. Therefore, redefining proper threshold limits of rainfall and understanding other geological factors are necessities to reduce future incidents.

Keywords: Cut-slope Failures, Heavy Rainfall, Threshold Values

1. Introduction

A geological hazard is a natural geological phenomenon that can threaten human lives and property. Earthquakes, volcanic eruptions, tsunamis, landslides, and subsidence are types of geological hazards. A disaster is a sudden, catastrophic event that seriously interrupts the functioning of a community or society and causes human, material, and economic, or environmental losses. Sri Lanka has been prone to natural disasters commonly caused by floods, cyclones, landslides, droughts, and coastal erosion for generations, with increasing losses to life and property in the past few decades. The movement of a mass of rock, debris, or earth down a slope as a result of both natural and human-induced factors is generally termed a "landslide" (Cruden, 1991). Landslides are considered common in the hill country of Sri Lanka, which is generally 300m above the Mean Sea Level (MSL). But they may take place on steep slopes at lower elevations too. For the occurrence of landslides or any type of mass movement, certain conditions must be present. The hill country of Sri Lanka gets rainfall of over 2000mm per annum and consists of rocks that are prone to high rates of weathering, eventually producing the clay-rich overburden. Intense rainfall is the causative factor for most of these landslides. The increasing trend of population growth in the country has adversely affected the stability of natural slopes due to various human activities. Cut-slope failures and slope failures are disasters that result from modifications to the natural slope. Among all the types of land failures, cut-slope failures have been identified as one of the most frequent and widespread manmade disasters in the mountainous terrain of Sri Lanka (Jayalath et al., 2018). Over the last few years, human activities such as excavation of slopes, loading of slopes at their crests, improper drainage systems, deforestation, artificial vibration (blasting, piling, etc.), and water leakage from utilities have significantly contributed to the increase in cut-slope failures in the Central Highlands. Removal of toe support of natural slopes, increasing water saturation and pore water pressure reduces the suction and shear strength of soil mass, which leads to cut-slope failures. However, the exact place and time of mass movement-related disasters cannot usually be predicted with any degree of certainty. In an ideal world, all areas susceptible to such hazards would be well known and actions would be taken to either avoid triggering the problem if it is human-related or avoid occupying such areas if they are prone to natural hazards.

Overwhelming the increasing threat and potential risk reduction of landslide disasters are the present-day challenges faced by the geologists working in the disaster management sector of Sri Lanka (Jayasinghe, 2016). The National Building Research Organisation (NBRO) of Sri Lanka has identified 10 administrative districts prone to landslides, specifically Badulla, Nuwara-Eliya, Rathnapura, Kegalle, Kandy, Matale, Kaluthara, Galle, Matara, and Hambanthota (NBRO 1995, Jayalath et al., 2016). Currently, NBRO has initiated a multidisciplinary approach for landslide risk reduction, including identification, awareness, early warning, mitigation and law enforcement (Bandara and Jayasinghe, 2018).

As an initial step to overcome the landslide damage in Sri Lanka, in 1991, NBRO introduced a numerical evaluation system for landslide hazard zonation by studying 1200 landslides in Badulla and Nuwara Eliya districts (NBRO, 1995). The methodology considers major causative factors such as bedrock geology and geological structures, natural soil type and thickness, morphological slope angle (slope ranges), hydrology and drainage conditions, land use and management, and landform to analyse the landslide hazard level. Weights for each of these factors were given by statistical analysis and expert knowledge to develop landslide hazard zone maps (LHZM) (NBRO, 1995; Kumari et al., 2019).

Though the Landslide Hazard Zonation Mapping helps to identify the vulnerability of the landslides in an area, it does not forecast a landslide event. To minimize the damage caused by landslides, prediction of landslides is also important. Most of the Sri Lankan landslides and slope failures are triggered by intense rainfall. The NBRO team prioritized the factor, and after extensive research, a method for issuing landslide early warnings based on LHZM and site investigation reports was developed. It was decided to add the rainfall data layer overlapping the LHZM and forge a relationship between rainfall and the landslide vulnerability of an area. NBRO is maintaining a system of 221 automated rain gauges. During the process, rainfall data from the Department of Meteorology and data acquired from the automated rain gauge network of NBRO are also taken into consideration. As a result, three regional early warning thresholds were identified as alert, warning, and evacuation.

Rainfall exceeding 75 mm within 24 hours and continuing - Alert Warning

Rainfall exceeding 75 mm within 24 hours and continuing - Warning

Rainfall exceeding 150 mm within 24 hours/75 mm within an hour and continuing evacuation warning (Bandara et al., 2008)

However, these threshold limits are generally applied to whole landslide-prone areas of Sri Lanka (Nawagamuwa and Perera, 2017). Even though rainfall intensity plays a major role in triggering landslides, the causative factors for the occurrence of cut-slope failures may vary.

Galle District has been declared as one of the landslide-prone Districts by NBRO (Rajapaksha et al. 2017). Considering the events recorded over the past few years, it is clear that because of recent modifications on natural slopes, cut-slope failures have become a dominant disaster surpassing landslides in the Galle District. Therefore, in every heavy rainfall event, a considerable number of cut-slope failures are recorded, while this is disturbing to the day-to-day life of people in the area. During the intense rainfall event in May 2021, such catastrophic events occurred in several Divisional secretariats in the Galle District. These events have made a significant impact on the socio-economic life of the society, the environment, etc resulting in a deterioration of the human lifestyle. The primary objective of the current study is to analyse disaster situations in Divisional Secretariats of Galle by an intense rainfall event in May 2021 and to identify relevant remedial measures to overcome the risk.

2. Methodology

Preliminary geological investigations were carried out from May 15th to May 18th, 2021, on reported failure incidents within the subjected Divisional Secretariats; Nagoda, Yakkalamulla, and Thawalama (Figure 01). According to the nature of the failures, investigated sites were categorized as cut-slope failures, slope failures, and potential cut-slope failures. Considering the field observations, the above hazards were classified into risk levels: low risk, medium risk, and high risk (Figure 02).

Available rainfall intensity data was collected from www.rainfall.nbro.gov.lk from 14.30 hours on May 10, 2021 to 15.30 on May 14, 2021. For the current study, data were acquired from the rain gauges located closer to the incident area (Nagoda (R48), Yakkalamulla (R46), and Neluwa (R50) (Figure 01). Using available 30 minutes rainfall data, hourly rainfall was analyzed accordingly. Rainfall data were analyzed only for Nagoda Divisional Secretariat considering the data availability. Since bedrock exposures are hard to observe in the studied locations 1:100,000 geological map of Alutgama- Galle was used to understand the surface geology of the area.

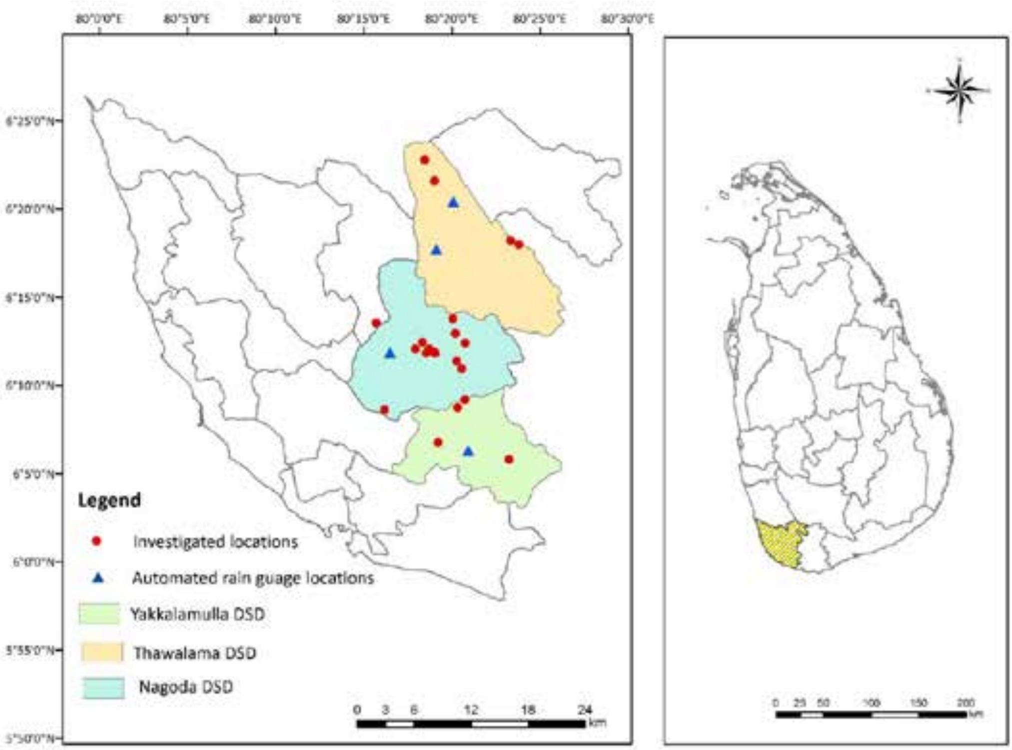


Figure 01: Study area and locations of considered automated rain gauges

Figure 02: Several cutting failures and destruction caused in Nagoda DSD

3. Results and Discussion

This study reveals that among the failures which occurred within the considered disaster period, 90% were cut-slope failures, 7% were slope failures, and 3% were potential cut-slope failures (Figure 03). Since no major landslide events were recorded and a high percentage of cut-slope failures were recorded, it is clear that not only heavy rainfall but also man-made disturbances to natural slopes, terrain conditions, and geomorphology of the area are responsible for triggering the slope instabilities.

Events are classified as high-risk, medium-risk, or low-risk based on the impact of failures on infrastructure and human life. Consequently, 80% of the total incidents were categorized as medium- risk failures, and 20% of the incidents were categorized as high-risk failures (Figure 04). Most of these failures have occurred due to improper drainage systems and a lack of awareness about construction practices.

Because of the surface geology of the area, 70.8% of the failures have occurred in the charnockitic gneiss layer, 25% of the failures in the garnet sillimanite biotite gneiss layer, and 4.2% of the failures in the garnetiferous quartzofeldspathic gneiss (Figure 05). Considering the relative weightings for major factors, subfactors, and factor classes based on the NBRO user manual 1995, locations that consist of charnockite as a subsurface layer have a higher weight (score of 5) than all other rock types. Therefore, it is clear that weathering products of charnokitic gneiss have a higher chance of generating cutting failures than other rock types.

Generally, well- developed weathered profiles are exposed in road cuts and construction excavations of engineered works. The underlying rocks have undergone chemical weathering, and weathered products of varying degrees are invariably found in situ, above the bedrock. Weathering affects almost all the engineering properties of rocks, and in most cases, the effect of the weathering of parent rock influences both the strength and stability of rocks and weathering products (Jayawardena and Izawa, 1994).

Usually, the main causative factor for the occurrence of landslides is rainfall, and the threshold limit for occurrence is considered to be 75 mm (Bandara et al. 2008). Nonetheless, this study reveals that all the cut-slope failures have occurred below the threshold limit of 75 mm, and henceforth, the threshold limit of 75 mm cannot be considered for cut-slope failures within the study area (Figure 06 & Figure 07).

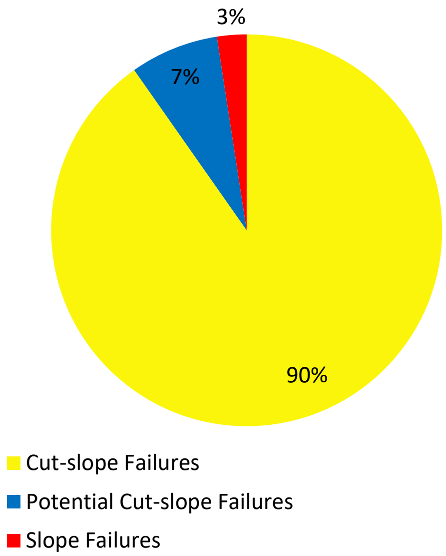


Figure 03: Types of failure occurred in the considered divisional secretariats

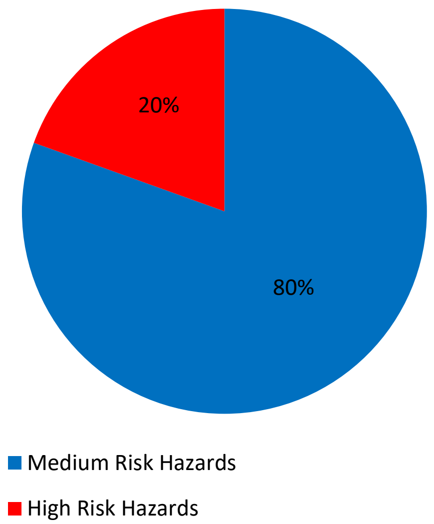


Figure 04: Percentage of failure distribution within the hazard categories

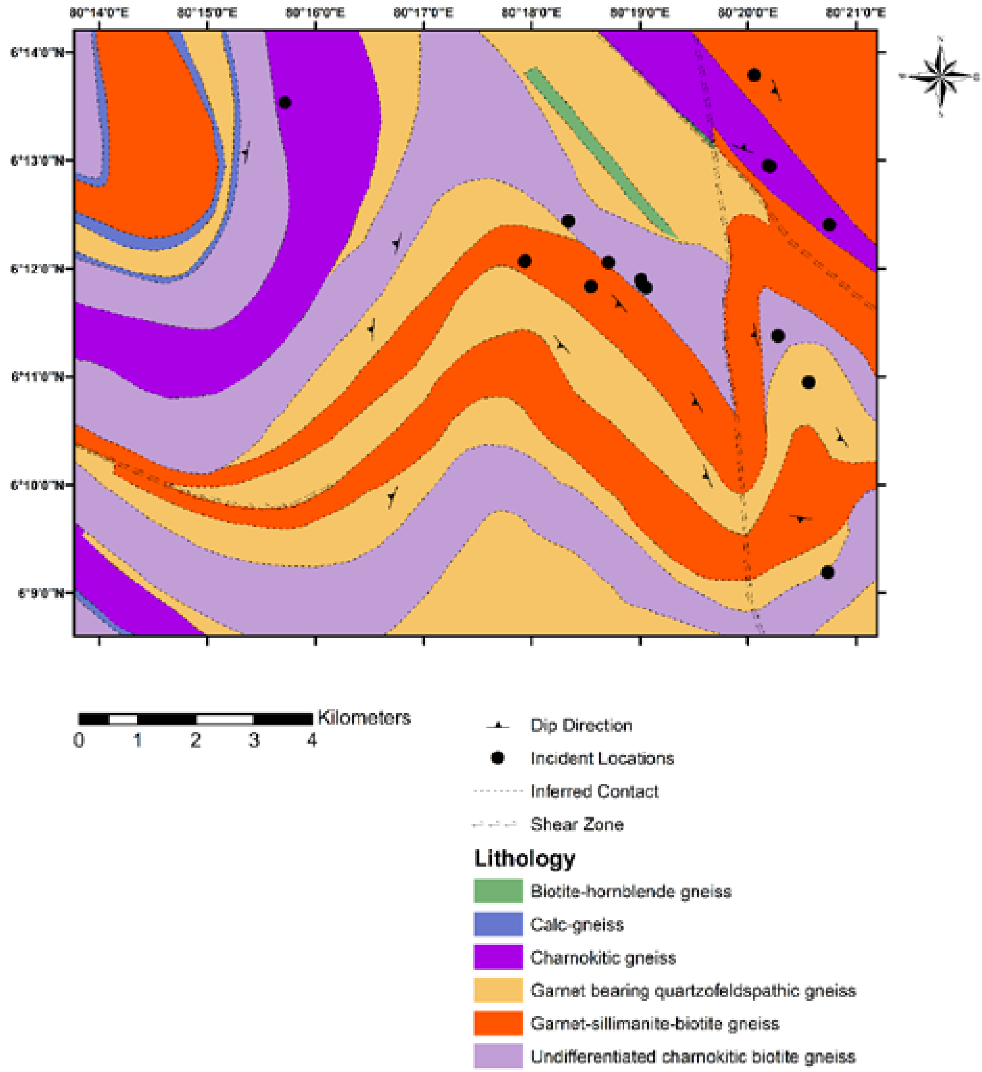


Figure 05: Surface Geology of the studied area (Source: 1:100,000 Geology map of Aluthgama-Galle, Sheet number 19, by Geological Survey and Mines Bureau)

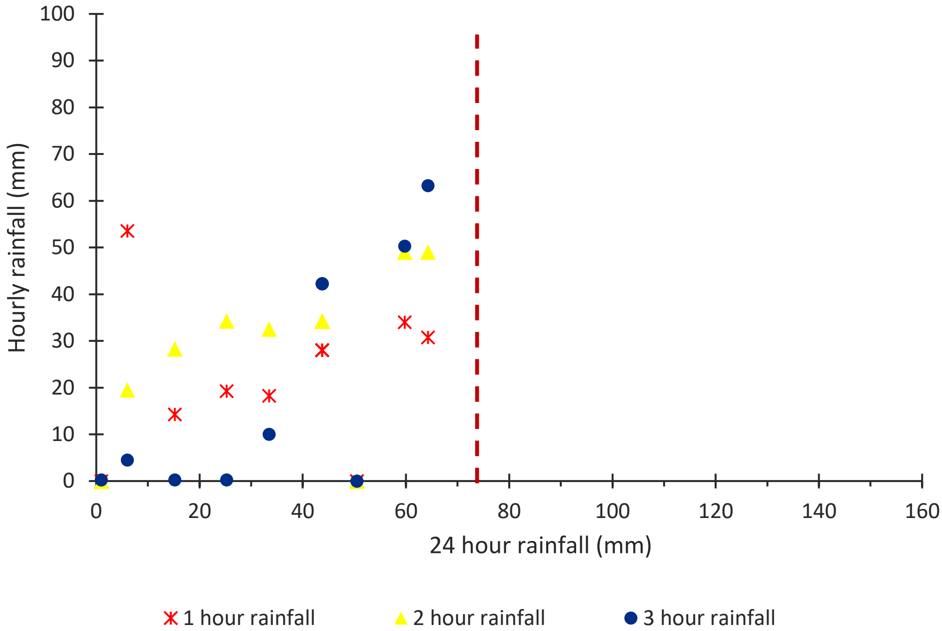


Figure 06: Effective rainfall for 24 hours vs hourly rainfall

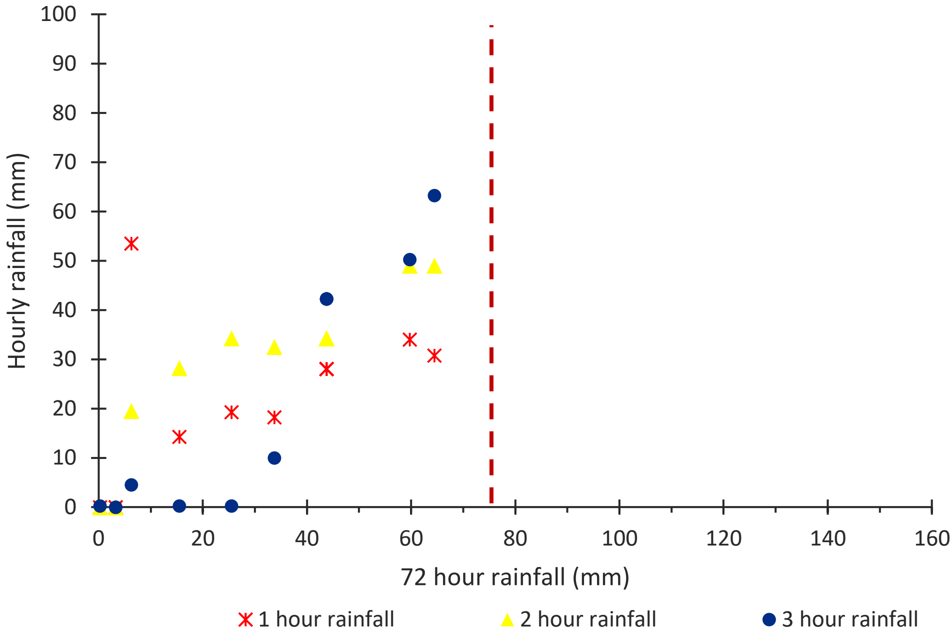


Figure 07: Effective rainfall for 72 hours vs hourly rainfall

4. Conclusion

Almost all the disastrous events that occurred around the rainfall event of Mid May 2021, are minor failures such as cut-slope failures and very few of them are slope failures. Most of the failures are in the medium- risk category. Results of the present study revealed that 70.8% of failures occurred on weathered products of charnockitic gneisses which give high values on the weighting system of the LHZM preparation procedure.

However, according to the present study, defined threshold rainfall values for landslides are no longer applicable for cut-slope failures in the study area, which implies that heavy rainfall is not the only primary causative factor for such events. Therefore, the results of the study lead to the requirement of understanding the main causative factors for such hazards and the necessity of developing a proper method to define threshold values for minor failures to reduce the risk in vulnerable areas. Furthermore, implementation and practice of proper building construction guidelines among the community and community-based awareness are important to reduce the risks.

5. References

1. Bandara, R.M.S., (2008) Landslide early warning in Sri Lanka, Regional Seminar on experience of geotechnical investigations and mitigation for landslides, Bangkok, Thailand
2. Bandara, R.M.S and Pathmakumara Jayasinghe (2018) Landslide Disaster Risk Reduction Strategies and Present Achievements in Sri Lanka Geosciences Research, Vol. 3, No. 3, August 2018 https://dx.doi.org/10.22606/gr.2018.33001
3. Cruden, D.M., (1991) A simple definition of a landslide. Bulletin of the International Association of Engineering Geology 43, pp 27–29 https://doi.org/10.1007/BF02590167
4. Jayalath., D.R.K., Weerasinghe, N.C., Bandara D.M.P.C., Rankoth R.P.I.T., Bandara, R.M.S., and Indrathilake, H.M.L. (2016) Landslide situation on Mid of May 2016 in Kegalle District, Sri Lanka, International Symposium 2016, National Building Research Organization, pp 213-219
5. Jayalath, D.R.K., Jayawardena, D.U.I., Ihalagedara, D., and Indathilake, H.M.L. (2018) Detailed investigation of road cutting failure-case study from Dehiovita-Deraniyagala-Nooriya road (B093) in Kegalle district, Annual Symposium 2018, National Building Research Organization, pp 26-34
6. Jayawardena, U. de S., and Eiji Izawa, (1994) A new chemical index of weathering for metamorphic silicate rocks in tropical regions: A study from Sri Lanka, Engineering Geology 36, pp 303-310
7. Kumari, M.A.K., Rajapaksha, R.M.S.D., Bandara, R.M.S., (2019) Overview of Current Landslide Hazard Zonation Mapping Methodology Utilize in Sri Lanka, Proceedings of the 8th CECAR, Tokyo
8. Nawagamuwa, U.P., and Perera, L.P., (2017) Recommending Rainfall Thresholds for Landslides in Sri Lanka, 4th World Landslide Forum, pp 267-272

9. Rajapaksha, R.M.S.D., Kumari, M.A.K., Hapuhinna, H.K.D.W.M.I.U.K., (2017) Assessing the predictive power of existing landslide hazard zonation methodology: A case Study- Rathnapura and Kaluthara Districts, Symposium, National Building Research Organisation
10. User manual on landslide hazard zonation mapping; NBRO (1995), National Building Research Organisation, Colombo.

Pullout and Creep Behavior of Soil Nailing - A Case Study

PADLS Chandrasiri[1], HR Maduranga[2]

[1]Engineer, National Building Research Organisation
[2]Senior Engineer, National Building Research Organisation, Sri Lanka

Abstract

Strengthening the unstable cutting slope using soil nails is a popular method in Sri Lanka due to the attractive benefits of simple and fast installing techniques. This paper presents several case studies on soil nail pullout resistant test details based on the several project of road side vertical cutting slope stabilizations using soil nailing technology.

Proper assessment of the soil nail behavior between the nails and the surrounding soil will contribute to the safe and economical design of the reinforced soil structure. At present, the safety factor is adapted to soil nailing design and analysis, however, some soil nailed slope, which are designed, in compliance to the slope guidelines end up with failure. For the current knowledge, there is limited information on the loss of the shaft friction in soil nailing due to creep and the research on the behavior of the soil nail is also teslimited. Hence, in order to provide additional information on the behavior of the conventional soil nailing system, the bore holes and pull-out test data were collected from the various projects.

The parameters measured are soil nail pull out resistance and displacement of soil nails under different loading. In addition, the creep behavior of the soil nail was a study based on the displacement under maintain period at maximum test load during the pullout test. The creep behavior of soil nail is causing the loss of tension in the soil nail and that affecting the performance of the engineered slope.

Keywords: ***Soil Nailing, Pull out Test, Load Cycles, Creep, Pull out Resistance, Displacement of a Soil Nail***

1. Introduction

Soil nailing technique was started to use in the early 1960s to improve the stability of slopes, using the principal of mobilization of tension load through the soil nails. The major element of soil nailing is soil nail reinforcement that has a yield strength of 460 N/mm^2 to 500 N/mm^2 (Bryne, 1998).

Cement grout sleeve is another major element that has a primary function of transferring stresses between the ground and the soil nail reinforcement "GEO (2017). Also, it is used to provide the corrosion protection for the steel bar. The water cement ratio of the grout that is used for the cement grout sleeve, typically has a range of 0.4 - 0.5 (Noor & Jamain, 2019).

Soil nail head is used to provide reaction for individual soil nails to mobilize tensile force. Also, it promotes local stability of the ground near the slope surface and between soil nails "GEO" (2017). The nail head is the threaded end of the soil nail that protrudes from the wall facing. It is a square shape concrete structure which includes the steel plate, steel nuts, and soil nail head reinforcement. Hex nut, washer, and bearing plate are attached to the nail head and are used for connecting the soil nail to the facing (Prashant & Mukherjee, 2010).

Slope facing is mainly used to prevent the erosion and the other adverse effect that can be happened to the slope. Shotecreting of slope and laying of coated metallic wire mesh along with coir mesh, are the two main slope facing methods used in Sri Lanka. However, when considering the concept of "green construction or sustainable building", laying high tensile wire mesh (HTWM) with coir mesh is the most recent slope facing construction method

2. Scope of study

The main scope of this study is,

1. to explain the fundamental mechanism behind the soil nailed system and the pull-out failure of a soil nailed system.
2. to present the results and observations that are taken from field pull-out tests carried out in major landslide mitigation projects in Sri Lanka.

3. Fundamental Mechanism of a soil nailed system

The frictional interaction between soil nail and the ground, reactions provided by soil nail head and facing, caused to develop the tensile force that are influenced by many factors "GEO" (2017). The factors affecting to develop tensile force in a soil nail can be recognized as Tensile strength of soil nail, Shear strength of soil nail, Bending capacity of soil nail, Inclination and orientation of soil nail, Shear strength of ground, Relative stiffness of ground and the soil nail, The size of nail head & Nature of the slope facing.

There are two fundamental mechanisms of nail-ground interaction, namely, the nail-ground friction that leads to the development of axial tension or compression in the soil nails, and the soil bearing stress on the soil nails and the nail-ground friction on the sides of soil nails that lead to the development of shear and bending moments in the soil nails (Noor & Jamain, 2019).

The failure modes of a soil nailed system, can be mainly divided in to two modes. They can be named as external failure mode and internal failure mode. The external failure mode can be identified when the potential failure surface is developed outside of the soil-nailed ground mass. The external failure modes can be divided in to three modes "GEO" (2017). They are Overall stability failure, Sliding failure & Bearing failure

The internal failure mode can be identified when the potential failure surface is developed within the soil-nailed ground mass. They can be identified as Failure of ground around soil nails, Soil nail head bearing failure, Local failure between soil nails, Tensile failure of soil nails, Pull-out failure of ground-grout interface (or ground - reinforcement interface), Bending or Shear failure of soil nails, Structural failure and connection failure of soil nails head & Structural failure and connection failure of facing "GEO" (2017).

Among the above failure modes, the pull-out failure occurs due to the lack of embedded length in to the passive zone to resist the forces that are developed to destabilize the slope. Therefore, it is important to find out appropriate pull-out resistance (grout-ground bond stress) and pull-out capacity in order to stabilize the slope against the Pull-out failure (Noor & Jamain, 2019).

Creeping of Soil nail can be contributed to happen the pullout failure. Creeping of soil nails occurs due to the gradual shearing at the point of soil–nail interaction. This shearing occurs due to the reactions that are formed against the tensile pull of the soil nail (Noor et al., 2014).

4. Pullout Test

The major scope of carrying out a pull-out test is, to take a verification on the design assumptions about the bond strength at the interface between the ground and the cement grout sleeve interface. It also gives a better understanding about the contractor's workmanship on soil nailing construction, suitability of the construction methods for the specific environment and potential construction difficulties. A pull-out test should be carried out a location where the pull-out resistant may be low or buildability of soil nail is most uncertain "GEO" (2017).

The nail that is used for the pull-out test should be installed according to the methods that are used for the working nails. In Sri Lanka, the typical grouted length is 2m.

Materials and equipment were used for the pull-out test at each site can be identified as Calibrated hollow plunger jack that has 60 tonnes or 120 tonnes maximum capacity complete with hydraulic pump, pressure gauge etc. Calibrated dial gauges with 150 mm stem travel and readable to 0.05 mm, Reference frame for setting the dial gauge, supporting system to retain the jack in position, Tools for preparation of ground to erect the testing arrangement.

Figure 01 : Pull-out test Arrangement

5. Test Procedure

The test consisted of loading the nail axially with the hydraulic jack in progressive steps while recording the load applied and the axial deflection of the soil nail with respect to the time. The loading was continued until the load applied reached the specified maximum test load for the loading cycles, the soil nail shows significant deflection at lesser load or the nail was broken during loading. After the maximum test load was applied and maximum holding time is maintained unloading was begun.

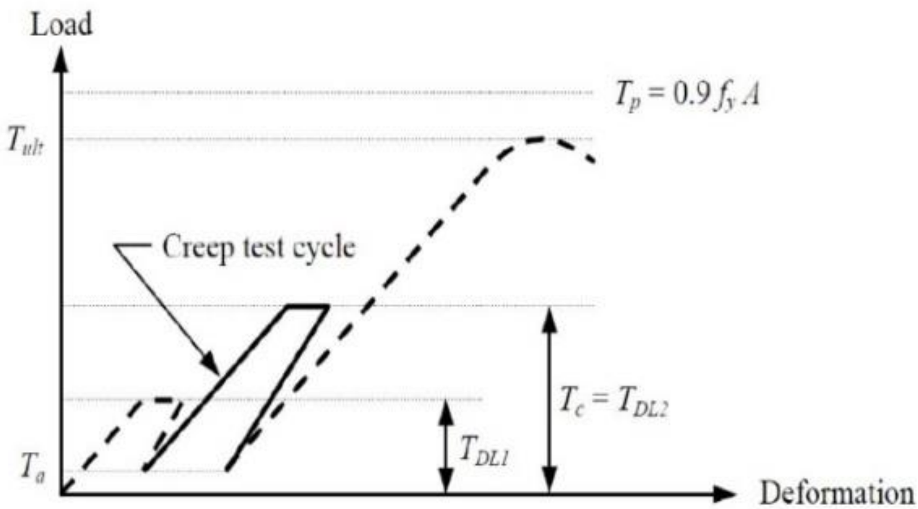


Figure 02 : Schematic Diagram of Load-deformation Cycle of a Creep Test as part of a Pullout Test

1. T_a (Initial Load), T_{DL1} and T_{DL2} (Two Intermediate load) were given in Figure 3
2. The test soil nail was loaded from T_a to the creep test load.
3. The creep test load (T_c) was defined as the allowable pullout resistance provided by the bond length of the cement grout sleeve of the test soil nail times the factor of safety against pullout failure at soil-grout interface (FSG), which was corresponding to the intermediate test load T_{DL2} for a pullout test.
4. The creep period shall be deemed to begin when Tc was applied. The load shall be maintained for Tc was applied. The load was maintained for 60 minutes for deformation measurement. During the creep period, the measurement was taken at time intervals of 1, 3, 6, 10, 20, 30, 40, 50 and 60 minutes.

A test soil nail shall be considered acceptable when:

(a) The difference of soil nail movements at 6 minutes and 60 minutes during the creep period does not exceed 2 mm or 0.1% of the bond length of the test soil nail, and

(b) The overall trend of creep rate (i.e., soil nail movement/ log time) is decreasing throughout the creep period.

6. Introduction to the Case Study

In this study, ten pullout test locations were taken from two major landslide mitigation projects that had been done in Sri Lanka. They are, Climate Resilience Improvement Project in Uva Province (CRIP - UVA) and Reduction of Landslide Vulnerability by Mitigation Measures Project (RLVMMP). Out of ten locations seven locations were taken from CRIP - UVA project that was implemented in Badulla district in Sri Lanka.

Reduction of Landslide Vulnerability by Mitigation Measures Project (RLVMMP) is implemented to stabilize 147 landslides prone areas around Sri Lanka. Among them, Ayagama Town Site, Kalawana Gamini School Site are located in Ratnapura District and Kumarikanda site is located in Kalutara District.

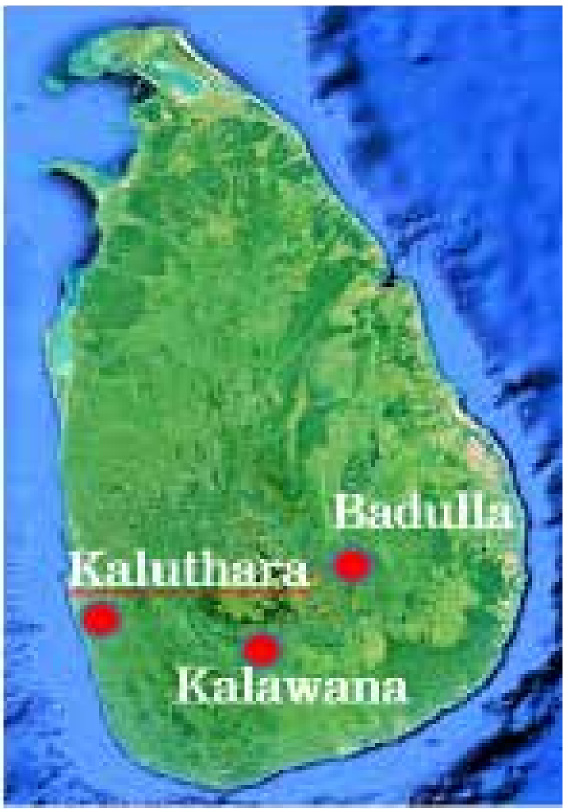


Figure 03 : Site locations

7. Methodology

Field pullout resistance of each ten locations is taken to analyze them with calculated pullout resistance of them. Pullout resistance are calculated by assuming the soil parameters for each site, taking the judgements from filed investigations that were carried out around the areas where the sites are stablished. After the judgements, Cohesion of soil (c) is taken as the 10 kN/m², the friction angle of soil (φ) is 300 and the unit weight of soil (γ) is 18 kN/m³ for all sites.

The maximum field pullout resistance is calculated using the peak pullout force that is taken from field pullout test by dividing it from the active surface area of the soil nail.

$$P_r = \frac{p_f}{\pi DL}$$

Where: P_r - The Maximum Field pullout resistance, p_f - Peak pullout force, D - Diameter of the drilled hole, L - Bond Length of the soil nail

Following equation is used to calculate the pullout resistance.

$$\tau = c + \sigma \times \tan(\phi)$$

Where: τ - Pullout resistance, *c* - Cohesion of soil, σ - Overburden pressure at the mid of the soil nail, Ø - Friction angle of soil

The calculated pullout resistance and maximum pullout resistance are analyzed in different methods to evaluate the pullout and creep behavior of each site. Following table interpret the details of each test nail and the methods that are used to evaluate the pullout and creep behavior.

Table 01 : Summary of the test nails

Location	Nail No Nos	Dia mm	Hole Dia mm	Length m	Bond Length m	Tested Date	Avg depth m
Badulla (14+850)	TN-1	25	100	6	2	18-Oct-21	1.00
Badulla (14+850)	TN-2	25	100	6	2	19-Oct-21	2.10
Badulla (14+700)	TN-2	25	100	6	2	17-Oct-19	3.49
Badulla20+400)	TN-2	32	125	8	2	24-Oct-21	3.78
Badulla (14+700)	TN-3	25	100	6	2	23-Oct-19	4.39
Badulla (14+850)	TN-3	25	100	6	2	18-Oct-21	4.50
Badulla20+400)	TN-1	32	125	8	2	22-Oct-21	5.91
Kalawana (GCC)	TN-1	32	125	12	2	22-Jun-21	6.10
Badulla (14+700)	TN-1	25	100	6	2	16-Oct-19	6.87
Kaluthara	TN-1	25	125	6	2	6-May-21	7.90
Ayagama	TN-1	32	125	8	2	7-May-21	9.50
Kalawana (Town)	TN-1	25	125	12	2	18-Feb-21	10.11

Table 02 : Load Cycle, Axial displacement and Load at failure

Location	Nail No	Avg depth	Load - Displacement					Load at failure
			Cycle 1		Cycle 1		dΔ	
	Nos	z	(T_{DL1})	d1	(T_{DL2})	d1	d2-d1	Pf
Badulla (14+850)	TN-1	1.00	34.00	0.02	50.00	0.02	0.00	250.0
Badulla (14+850)	TN-2	2.10	30.00	0.00	45.00	0.07	0.07	170.0
Badulla (14+700)	TN-2	3.49	33.00	0.00	50.00	0.02	0.02	140.0
Badulla20+400)	TN-2	3.78	47.00	0.07	70.00	0.12	0.05	170.0
Badulla (14+700)	TN-3	4.39	34.00	0.03	50.00	0.00	-0.03	190.0
Badulla (14+850)	TN-3	4.50	32.00	0.06	48.00	0.02	-0.04	150.0
Badulla20+400)	TN-1	5.91	56.00	0.08	70.00	0.06	-0.02	250.0
Kalawana (GCC)	TN-1	6.10	65.50	0.13	95.10	0.37	0.24	120.0
Badulla (14+700)	TN-1	6.87	30.00	0.07	47.00	0.00	-0.07	170.0
Kaluthara	TN-1	7.90	53.00	0.00	74.40	0.56	0.56	86.8
Ayagama	TN-1	9.50	65.50	0.03	95.10	0.07	0.04	153.0
Kalawana (Town)	TN-1	10.11	70.00	0.10	111.80	2.03	1.93	177.5

Pf - Pullout load at failure

Table 03 : Calculated Pullout load

Location	Nail No	Load at failure P_f	Pullout resistant q_s	Over burden pressure σ_v	Calculated pullout resistant q_{sc}
Badulla (14+850)	TN-1	250.0	397.89	18.00	20.39
Badulla (14+850)	TN-2	170.0	270.56	37.80	31.82
Badulla (14+700)	TN-2	140.0	222.82	62.82	46.27
Badulla20+400)	TN-2	170.0	216.45	68.04	49.28
Badulla (14+700)	TN-3	190.0	302.39	79.02	55.62
Badulla (14+850)	TN-3	150.0	238.73	81.00	56.77
Badulla20+400)	TN-1	250.0	318.31	106.38	71.42
Kalawana (GCC)	TN-1	120.0	152.79	109.80	73.39
Badulla (14+700)	TN-1	170.0	270.56	123.66	81.40
Kaluthara	TN-1	86.8	110.52	142.20	92.10
Ayagama	TN-1	153.0	194.81	171.00	108.73
Kalawana (Town)	TN-1	177.5	226.00	181.98	115.07

8. Interpretation of test results

Analysis has been done in three different methods in order to interpret the results and observation.

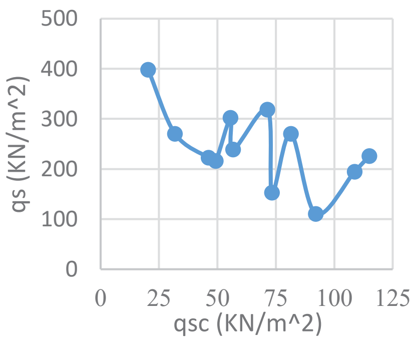


Figure 04 : qsc vs qs

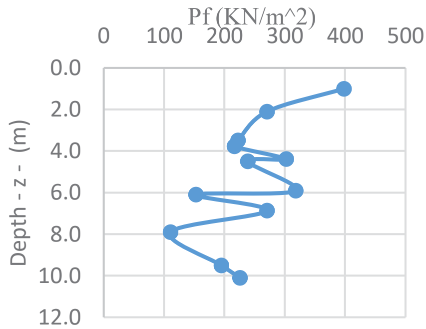


Figure 05 : Pf vs z

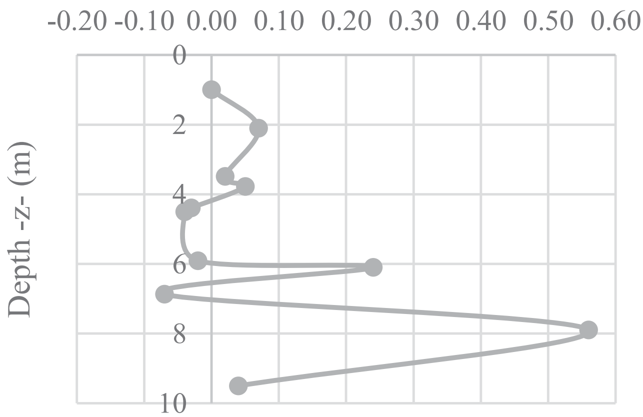


Figure 06 : Displacement difference Cycle 2 and Cycle 1 vs Depth

1. Variation of Maximum field pull-out resistance with the change of calculated pull-out resistance

Figure 4 shows that, at every test nail location the Maximum field pull-out resistant is higher than the calculated pull-out resistant. The factor that changes the two- pull-out resistance is at the range of 1.2 - 8.5. The location that are situated in Badulla District has a better factor than the locations that are situated in Ratnapura and Kalutara Districts. It gives an idea about changing of the strength and the other factors of soil at different districts in Sri Lanka.

2. Variation of Maximum field pull-out resistance with the change of Overburden height at the mid of soil nail

Figure 5 shows that the maximum pull-out resistant at the field decreases when the overburden height is increased. According to the plotted graph the pull-out resistance is not decreased gradually due to the variation of conditions in different sites.

3. Variation of Difference of creeping between the two cycles with the change of Overburden height at the mid of soil nail.

Figure 6 shows the difference of displacement at maximum load of each test cycle changing with the overburden height of the nail. This shows that the failure due creeping is not happened at any of the site in each maximum loads of the cycles. According to the plotted graph the displacement difference is much higher when the depth increases but it is not varied gradually.

9. Conclusion

The maximum field pullout resistance is much higher than the calculated pullout resistance at every test nail location that indicated the suitability of design assumptions and quality of the contractor's workmanship are at the acceptable level. Therefore, it can be concluded that the mitigation measures that were taken to reduce the landslide vulnerability are at the highly acceptable level.

Creeping and the pullout resistance are not varied gradually with the overburden height of the soil nail.

10. References

1. Bryne, R. J. (1998). Manual for design and construction monitoring of soil nail wall. Federal Highway Administration.
2. Hong Kong Geotechnical Engineering Office. (2008). ***Guide to soil nail design and construction***. Geotechnical Engineering Office, Civil Engineering and Development Department, The Government of the Hong Kong Special Administrative Region.
3. Noor, M. J. M., & Jamain, M. F. (2019). ***Pull out and creep behaviour of soil nailing*** - a case study. Pull Out and Creep Behaviour of Soil Nailing - A Case Study. Published.
4. Noor, M. M., Saidin, M. A., & Tahir, S. M. (2014). Effectiveness of hybrid anchor soil nails in stabilizing slopes and stability assessment based on mechanics. ***Landslide Science for a Safer Geo-Environment,*** 707-713.
5. Prashant, A., & Mukherjee, M. (2010, August). ***SOIL NAILING FOR STABILIZATION OF STEEP SLOPES NEAR RAILWAY TRACKS.*** Research Designs and Standards Organization (RDSO), Lucknow.

Study on Compact Settlement Design Concepts in Post-Disaster Involuntary Resettlements

MSN de Zoysa[1]

[1]Scientist, National Building Research Organisation, Sri Lanka

Abstract

Rapid increase of disaster induced and development induced involuntary resettlements is a critical issue in worldwide. Within the Sri Lankan context, it can be identified both kinds of resettlement projects. When considering the identified concerns in the resettlement process, housing became a more critical and important aspect throughout the entire process. As the resettlement is a far more a sensitive process beyond providing shelters, it should address the multidimensional requirements of the resettling community as well as the host community in different perspectives. However, still there is a distrust on the sustainability of the involuntary resettlements in long term.

In the present context of post-disaster resettlements, there is a general conception of communities opting for single storey, stand-alone type of housing which requires large land parcels for resettling which is a challenge for land supply in the future. Further, due the use of valuable, productive agricultural lands for the reconstruction of new settlements, the economic loss and the degradation of agricultural land could cause some serious problems in the future which could not be exactly estimated from now.

Therefore, there is a futuristic requirement of providing different types of compact settlements for post-disaster involuntary resettlements. But, the currently available studies and research done to explore the response to compact settlements and on principles and concepts for making successful compact settlements are insufficient within the Sri Lankan context. Hence, it is required to identify and analyze the practical issues, and actual requirements of housing in the involuntary resettlement, and address to those issues and needs of the resettling community in compact settlements to make the resettlements sustainable in long term.

Keywords: Post-disaster Resettlement, Compact Settlements, Sustainability

1. Introduction

Resettlement is a population transferring system due to natural disasters, wars, ethnic or religious disputes and development projects of a country, resettlement can be divided into two categories namely; development induced resettlements and disaster induced resettlements. During the past two decades, floods, landslides and the tsunami were the most critical types of natural disasters that resulted in a considerable number of post disaster resettlements in Sri Lanka.

A disaster is a term describing a whole range of distress situations, both individual and communal. (Moe & Pathranarakul, 2006) Emergency Events Database (EM-DAT) statistics show that, the number of disasters triggered by the occurrence of natural hazards has accelerated worldwide (Correa, 2011). Natural disaster is a serious disruption of the functioning of a community or a society causing widespread human, material, economic or environmental losses which exceed the ability of the affected community or society to cope using its own resources. (UN-ISDR, 2009) Parallel to the increase of natural disasters, the number of post disaster resettlements are also increasing.

Through all the post disaster resettlement programmes, the government was expected to uplift the living standards of the disaster affected communities in a sustainable manner during its processes. As resettlement is a complex, multidimensional process that transcends the housing aspect, far more sensitive to the complexities of the resettlement process is needed in post disaster resettlement. It is not, for example generally recognized by reconstruction authorities that the consequences of resettlement itself may even be more grievous than the impact of the disaster (Smith, 1991). As Badri and others (2006) highlights, well-planned and managed resettlement process can produce positive long-term development outcomes. Conversely, if it is poorly planned, it will create significant adverse impact on affected communities and in some occasions in the host community.

Natural disasters often create large scale property damage and prompts for effective and expensive resettlement programmes. However, research studies have shown that resettlement efforts following natural disasters are often, uncoordinated, sluggish and ineffectively managed. According to (Oliver Smith, 2009), in general, resettlement or relocation processes are poorly planned, inadequately financed and incompletely implemented turning these projects into “Development of Disasters”.

In the disaster affected resettlements, people have no realistic choice, but to move. Therefore, the built environment is the platform from which to improve societal disaster resilience. (Bilau A.A., Witt E. & Lill I., et.al., 2015) Accordingly, it highlights that, the built environment plays a central role in both casualties and economic losses. Hence, it is required to confirm that the post disaster resettlement housing fulfills the above requirements of the resettled communities.

In the disaster management cycle, there are four major section as preparation, response, recovery and mitigation. When considering the identified concerns in the disaster management cycle, the recovery phase specifies both restoration and reconstruction processes. Accordingly, the resettlements which are directly related to reconstruction can be identified as an important factor. It means, in the resettlement process, housing became a more critical, important and sensitive aspect throughout the entire process. Subsequently, it becomes the responsibility of the professionals who engaged in the resettlement process to make the resettlement projects sustainable.

2. Disasters and Post-disaster Resettlement in Sri Lanka

When considering the natural disasters in Sri Lanka, floods, landslides, tsunami, high winds, forest fires, droughts and lightening are the most commonly identified natural disasters. During the past two decades, floods, landslides and the tsunami were the most critical types of natural disasters, that resulted, in a considerable number of post disaster resettlements in Sri Lanka.

As a focal point in disaster affected resettlements in Sri Lanka, NBRO identified 14,032 families in ten districts namely 3,683 in Badulla, 2,284 in Ratnapura, 2,230 in Kegalle, 1,696 in Kalutara, 1,347 in Kandy, 1,386 in Nuwara Eliya, 840 in Matale, 280 in Matara, 177 in Galle and 109 in Hambantota to relocate in safer locations. In the identification of the families, it included the families who were directly affected by the natural disasters and the families which are living in identified high-risk areas.

According to the discussions had with the disaster affected communities, there is a general conception of communities opting for single storey, stand-alone type of housing which requires large land parcels for resettling which is a challenge for land supply in the future.

Also due to the most of flood and landslide disaster affected relocation sites are in hilly areas and sloppy terrains, the land development costs are also very high. Accordingly, the per house cost is also increasing during the construction phase, and the available limited safer lands are also decreasing rapidly. Not only that, but also the people are losing their livelihoods in the new settlements as well.

According to Ismail F. and others (2014), quality of life has two major indicators, such as; Objective indicators and subjective indicators. It mentioned, physical attributes of the house, physical environment, surroundings, and facilities as the objective indicators. And human feelings, thoughts and behavior towards the culture, and experience in the house as the subjective indicators.

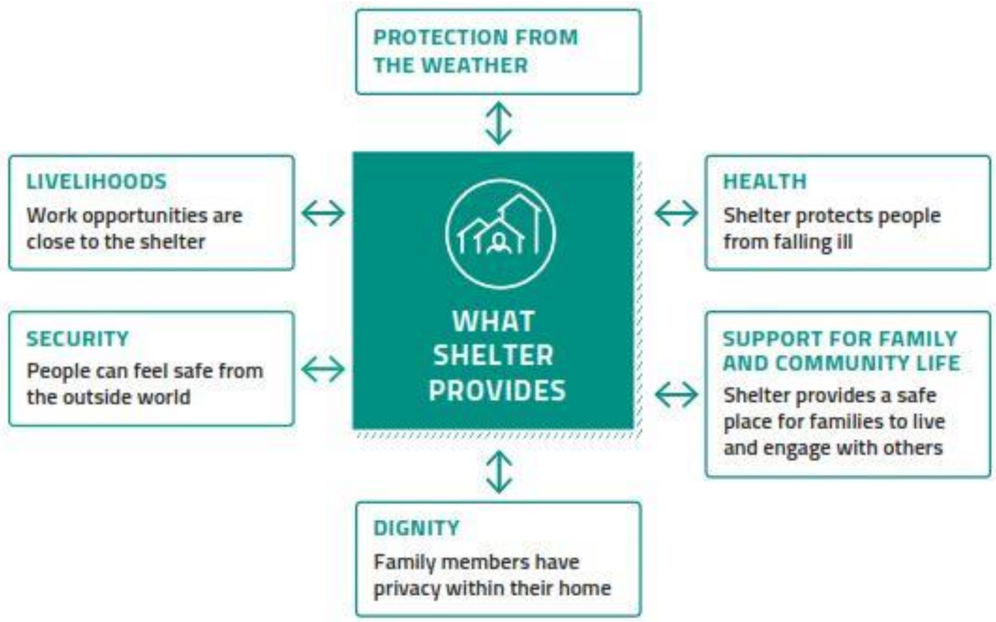


Figure 1: What shelter provides (Source - The Sphere Handbook, 2018)

3. Theoretical Conceptions of Home

Researchers in many disciplines have examined the concept of home and a considerable literature articulates the wide range of its meanings (Heidegger 1954; Bachelard 1964; Canter 1977; Csikszentmihalyi and Rochberg-Halton 1981; Alexander 1985; Altman and Werner 1985; Dovey 1985a; Rybczynski 1986; Lawrence 1987; Despres 1991; Moore (1998). Most significant of these research outcomes is the acceptance that home is central to the human experience of the world and that a 'sense of home' is an essential component of one's being. Although there is considerable cultural variation, it has been argued that there is no other concept so widespread and easily understood by all people as 'home' (Dayaratne, 1992). In most languages and cultures and in everyday experiences, home is a fundamental and essential conceptual entity. People understand the meaning of home effortlessly; almost unconsciously, they employ it to anchor their 'being in the world'.

The literature suggests two distinct aspects of the concept of home: spatial and social.

However, these two facets are not mutually exclusive and cannot be separated. In essence, a home is a rudimentary 'place' in human life. Home-making is a fundamental activity which anchors an individual in the world within the universe of space, things, people and events in which he or she exists (Bachelard, 1964). It enables an individual to establish a point of orientation to the rest of the world and organize social and spatial relationships around a referential geographical location in space (Tuan, 1977). Home is considered to consist of the history and memories of the family and is the storehouse for the physical, social, psychological or emotional wealth of its occupants (Lawrence, 1987, 1991). Home is thus made in the process of living and is in a constant process of consolidation and transformation (Habraken, 1983).

For many people, home or its equivalent essentially means the location where one 'dwells' and which affords opportunities to claim a sense of belonging (Heidegger, 1954). It is a place to return to, a place to defend against intruders and a place to contain one's belongings. Articulating this, Bachelard (1964) writes that home is "our corner of the world … our first universe, a real cosmos in every sense of the word."

To understand the meaning and significance of home, it is also necessary to understand the significance of 'place' in human experience. Seagart (1985) points out that home is a much more restrictive and place-based idea than dwelling. The idea of a home signifies the location in which the main activities of daily life are conducted and therefore carries symbolically charged meanings. Canter (1977) proposes that conceptualizations of place are the atomic units of human experience. He argues that in the human conception of the world as a collection of interlocking and encompassing places, home is the anchor that binds the experiential entities of physical enclosure, social relations and psychological feelings.

Homes and houses differ in that home is a 'place-based' concept, whereas the house relates essentially to the physical object and its location. (Dayarayne R. & Kellett P., 2008)

4. Concepts Practicing in Involuntary Resettlements

As explained above, it is required to control the sprawling development around the country. According to the UN sustainable goals, "Sustainable Cities and Communities" (Make cities and human settlements inclusive, safe, resilient and sustainable) mentioned as one of the most important factors of the development of a country. Consequently, post disaster resettlements are also important in this process.

When considering the National Housing Policy in Sri Lanka, it stated that their goal is; "To ensure the right to live in an adequate, stable, qualitative, affordable, sustainable, environment friendly and secure house with services for creating high living standards on the timely needs of the people."

- Objectives of National Housing Policy
- Qualitative and quantities improvement of the housing stocks
- Enhancing monetary supply in housing effectively and vibrant of the national economy
- Encourage vertical housing development
- Direct involvement of the government for vulnerable group
- Strengthening the asset based of the community
- Enhance the public private partnership in housing

4.1. Expected Outcomes of the National Involuntary Resettlement Policy (NIRP)

As highlighted in the National Involuntary Resettlement Policy (NIRP), the resettlement process should restore the affected community's living standards and integrate into their new settlements. Also, it should ensure that, the affected people are not negatively impacted. Further, it describes, those people who are living in vertically developed resettlements, have key issues in landlessness, joblessness, homelessness, marginalization, food insecurity, loss of access to common property resources, increased morbidity and mortality and community disarticulation.

Mainly, the resettlement implementing plan targets to;

- Replace lost fixed assets
- Restore living standards
- Restore livelihoods
- Restore social networks and common property resources.

4.2. Concept of Build Back Better (BBB)

'Build Back Better' is a concept introduced to deliver resilient, sustainable, and efficient recovery solutions to the disaster affected communities in reconstruction and recovery process. Through that, it is expected to make communities stronger and more resilient after the disasters. Further, it should provide an opportunity to not only reconstruction of the damages, but also to improve physical, social, cultural, environmental, economical, etc. conditions of the communities, and resilient for future disasters. As per Mannakkara S, Wilkinson S. & Francis T.R. (2014) stated, this concept was termed "Build Back Better" suggesting that successful recovery of communities following disasters needs to amalgamate the rehabilitation and enhancement of the built environment along with the psychological, social, and economic climates in a holistic manner to improve overall community resilience.

When considering the guidelines in United Nations Disaster Relief Organization's "Principles for Settlement and Shelter", "Post-Tsunami Recovery and Reconstruction Strategy" and "Build Back Better Guiding Principles" in Sri Lanka, has analyzed the Build Back Better concept in different sections. Accordingly, the reconstruction and recovery section of the concept has five sub concepts as follows.

Table 01 : Key concerns of built back better concept and expected outcomes

No.	Concept	Expected Outcomes
01	Risk reduction	Reducing disaster risks in communities to improve the physical resilience in the built environment.
02	Psychological recovery	Supporting psychological recovery of affected communities, and assist communities with moving forward.
03	Economic recovery	Supporting economic recovery of the community and supporting livelihood regeneration and entrepreneurship.
04	Effective implementation	Better management of stakeholders and use of appropriate post-disaster legislation and regulation.
05	Monitoring and evaluation	Monitor and ensure compliance of recovery activities, and obtain lessons learnt for future improvements.

5. Methodology and Approach

The approach to this study is twofold. Firstly, it reviewed the drawbacks prevailing in the currently available involuntary compact resettlements, and subsequent project implementation strategies. Accordingly, it covered both disaster induced and development induced involuntary compact resettlements in the local context. Secondly, it outlined the areas of design considerations that needs to be developed to increase the level of sustainability of compact settlement building typologies in different cultural and physical contexts.

6. Pros and Cons of Vertical Living in Involuntary Resettlement Programmes in the Local Context

6.1. Site Selection

Large scale housing projects that provide housing to a maximum number of people required large plots, which were often available mostly in distant locations. As a result of this, the majority of the donor driven housing was developed in new suburbs or villages. Provision of infrastructure and services for distant settlements has been challenging. When services and livelihood opportunities are absent, people have been unwilling to relocate to these distant settlements. Therefore, development of infrastructure can be mentioned as an indirect recovery strategy. According to this scenario, increasing the number of apartment type housing will protect land form from urban sprawls and hazard development and provide more land for other uses. It also enables the appropriate infrastructure and services to be provided more efficiently to a higher population density. Hence, a relatively large scale of a scheme and dense population can be a positive factor for the creation of livelihood opportunities, and the resource provisions will be feasible and sustainable.

6.2. Economy and Livelihood

Linking the livelihood of the resettling community to the new settlements are also problematic in current apartment type resettlements. The successful rehabilitation is a result of combining local knowledge with technical expertise guided by national goals. Therefore, by increasing the involvement of community participation, the community will be able to address the shortcomings foreseen in the future (Ex: maintenance of the houses, etc.).

With involuntary resettlements, people face social, economic and physical challenges which may be positive or negative. According to the literature, it is observed that, several years after relocating, the resettled community has multidimensional stress in physiological, psychological, economic and social. Sometimes, they have relocated different community groups who came from different social contexts in one location. With this situation, both communities face difficulties in belongingness. Due to the provision of resettlement houses in apartments by following the house to house concept, without community consultation and participation, psychologically the people feel uncertainty.

Further, all the people who has resettled in the apartment are the people who lived previously in individual houses in ground floors. Therefore, the people have physiological issue of landlessness, and the sense of not owning a plot has an impact on their sense of ownership over the place they live in.

In addition to that, the resettled communities have negative impacts on the resettlements on capacity earn and their livelihoods due to the increase of distance to work.

Competitive attitude of the residents can be mentioned as a positive impact of the compact living. Accordingly, the residents are eventually leads to successful financial management systems, and improve the possibilities of individual developments with new dreams.

However, because of the distances to the work places and the unpleasing identity of the community, the young generation is in way of shifting to other places for permanent living. Further, the remaining young community is at a risk of rapidly attracted to drugs and alcohol which are freely available within the compound. Due to that, people feel unsafe within the apartment premises. This can be identified as an issue with the social environment. Therefore, it is required the intervention of the government or non-governmental institutions on introducing methods to change the society's attitude on the relocated community.

Further, the resettled community needs further information, knowledge and guidance on new self-employment opportunities.

6.3. Forming the Work Team, Assessment and Studies

In the involuntary resettlements, people's adaptation to the resettled location is highly important to the sustainability of the settlement. Therefore, the team of professionals who engaged in the resettlement process must consider on the methods how the relocated people adapt to their livelihood, education, service accessibility and economic, social and political life to suit the new physical and social environment.

According to the literature, people who are living in the relocated apartments are happy about the legal ownership of the houses, and with that, they feel they are in a safer legal place.

6.4. Layout Planning and Design

When considering the development of social interactions within the resettled community, the design is not much effective with the expectations of the community. Because, most of the women in the apartment had stronger social relationships in the previous location. Accordingly, they have lost their common informal gathering spaces. Further, their previous neighbours are living in different floors, and it is also became a reason to decrease the social relationships. Not only that, but also the opportunities to meet and greet etc. have changed in vertical developments. The changes of meeting friends and neighbours vary due to the form of vertival circulation and location of houses in different floors that reduces the visual and physical accessibility among the residents. Therefore, further research is required to explore such concepts and its implications on the social integration of dwellers.

However, growths of high-rise apartments have positive signs of the development. With that situation, people are in a mindset to develop economically. Consequently, they are purchasing several new furniture items with their requirements. But, they have another issue with the provided spaces inside the houses. With the limited space, people have to limit their needs to essential items of the houses. The economic growth and betterment of residents and their aspirations and need for improvements have to been accounted for the developments. The residents do not have the opportunity for incremental growth externally or even internally through space for furniture and other belongings. The growth of family size is yet another aspect to be considered and housing needs to be adaptable for such growth, allowing the options and opportunities for residents to grow and develop.

Moreover, when designing and providing common or public spaces (Ex: Play areas, etc.) it should define the community it will cater and what are the proposed developments for other social groups in different categories such as; age, gender, etc.

In addition to the above, it is identified that the community satisfaction in involuntary resettlements is a factor which depends on the people's past experiences of life. Therefore, when providing housing for a community, it is important to study, identify and apply the methods which can be used to create harmony in the relocated communities.

However, it is identified that, the relocated community is highly disappointed on the social and physical context of the new settlement. When considering the physical setting of the apartments, in most of the apartments, any stranger can easily get in to the apartments. This makes the residents unsafe. This happens mainly due to the improper arrangement of narrow roads and alleyways cross and near the apartment premises. With this, public open spaces, benches and shaded areas (Under shady trees) also became informal gathering spaces for strangers and it became harmful for the residents' privacy and security, and bounds the residents in their homes with less opportunity to enjoy their neighbourhood in safely.

In the apartment living, the residents are expecting ground floors or easily accessible upper floors. Also, the limitations of extending the provided spaces have caged the livelihood of the residents. Further, the gloomy spaces within the resettled context is a critical issue for the residents, and this also creates an unsafe environment. Rather than that, just providing unplanned common/public spaces created several social and cultural issues in apartment type housing.

The literature highlights that the residents of the apartments are unhappy with the floor areas of provided houses. Due to the lack of space for recreational activities, the young community automatically hang out mostly in common spaces.

Ex: Corridors, open spaces between apartments.

In addition to the above factors, the provision of infrastructure is also important. Due to the improper and unplanned drainage systems, and poor maintenance, it leads to urban flooding and pandemic situations like dengue, etc. Consequently, the residents have issue of the garbage disposal system, and there is no proper maintenance and responsibility to manage the garbage disposal. Other than that, it is identified that the lack of consideration among the livelihood of the resettled community in the pre-design phase also created several issues in the internal arrangement of the houses. As an example, lack of chimney spaces or exhaust fans were identified, and due to that, the residents have to face ventilation issues inside the houses.

When considering the internal arrangement of the distribution of shop houses within the apartment, there is a critical issue on the locations of the shop houses.

Ex:
- Some shops are located in upper floors, which are difficult for the residents to access.
- Due to not providing proper spaces for shops, people have converted the living rooms or bed rooms in to shops. Therefore, the residents of the shop houses have issues of the availability of spaces for their household activities. And the common corridor spaces are also have blocked.

Lack of proper methods to control the noise within the premises became another issue which is directly affect to the privacy of the residents. Further, according to the UDA regulations, the pets are not allowed in some apartments. But, some residents have pets in their houses who has taken from their previous locations, and some people are keeping dogs for their security. But, because of not providing a well-planned methods to keep animals, several social issues were arised and it leads to decrease the social relationships among the community.

When considering the education of the children, some people who lived in more noisy and crowded places before are happy with having a comparatively calm environment. But, with the distance to the schools, the residents are not happy with the new location, and can be identified as a negative impact.

7. Conclusion

From the above analysis, it is identified four major concern areas as the most sensitive considerations in involuntary resettlements as follows;

- Site selection
- Economy and livelihood
- Forming the work team, assessment and studies
- Layout planning and design

According to the above analysis, the residents are mainly disappointed among the social and physical environment of the context, and all are expecting more dynamic and peaceful living environment.

However, the major reason for that is the lack of connection between each community which has increased with the unplanned physical and social contexts of the settlements. Therefore, it is important to carefully manage the livelihoods throughout the entire reconstruction process in a sustainable manner. Otherwise the reconstructions will create a path to another disaster.

Therefore, to make the involuntary resettlement projects successful, it is required to study and observe the activity patterns of the community, and provide guidance on the use and maintenance of the spaces. Also, the design solutions should address positively to the entire resettled community as well as the host community to achieve the sustainability in long term.

8. References

1. Ashar F., Amarathunga D., & Haigh R. (2014). *The analysis of tsunami vertical shelter in Padang city,* Procedia Economic and Finance.
2. Ahmed I., & McEvoy D. (2010). *Post disaster housing reconstruction : Post occupancy case studies from Sri Lanka,* RMIT University, Australia.
3. Aminuddin A.M.R. & Yong G.K. (2009). *Study on Low Cost High Rise Urban Housing in Kuala Lumpur – Impact on Communities and Social Spaces,* Int. Journal for Housing Science, Vol. 33.

4. Cernea M. (2007). *Impoverishment Risks, Risk Management, and Reconstruction: A Model of Population Displacement and Resettlement.*
5. Godamunne N. (2013). *Development and Displacement: The National Involuntary Resettlement Policy (NIRP) in Practice,* Sri Lanka Journal for Poverty Analysis (CEPA)
6. Haigh R. & Amarathunga D. (2010). *An Integrative Review of the Built Environment Discipline's Role in the Development of Society's Resilience to Disasters,* Centre for Disaster Resilience, School of the Built Environment, University of Salford, UK.
7. Haigh R., Hettige S., Sakalasuriya M., Vickneswaran G., & Weerasena L. N. (2016). *A study of housing reconstruction and social cohesion among conflict and tsunami affected communities in Sri Lanka,* Disaster management and Prevention Journal, Vol. 25.
8. Iresha M., Lakshman, Herath D., Mohammad A. & Ekanayake A. (2016). *Experiences of a Relocated Community in Colombo: Case Study of Singhepura, Wanathamulla,* International Centre for Ethnic Studies.
9. Munasinghe N., (2013). *A Study on Planning Stages of Urban Resettlement (With Special Reference to Chithra Lane Resettlement Project: Colombo, Sri Lanka),* Proceedings of the Third International Symposium, Department of Social Sciences, University of Sabaragamuwa, Sri Lanka.
10. Pellinan S. S. (2012). *Outcomes of post tsunami reconstruction – a case study from Sri Lanka,* Faculty of Science, University of Helsinki.
11. Perera I. (2015). *Forced Evictions in Colombo: High-rise Living,* Centre for policy alternatives.
12. Vijekumara P.A. & Karunasena G., (2016). *Analysis on Resettlement Process: Landslide Disasters in Sri Lanka,* International Conference on the International Institute for Infrastructure Resilience and Reconstruction, University of Peradeniya.

Looking at Disaster Risk Mitigation in Development Perspectives, with Special Reference to Landslide Risk Mitigation in Sri Lanka

EMKS Ekanayake[1], PHCS Rathnasiri[2]

[1]Scientist, National Building Research Organisation, Sri Lanka
[2]Senior Scientist, National Building Research Organisation, Sri Lanka

Abstract

Sri Lanka as a tropical island located in the Indian Ocean and exposed to the Bay of Bengal receives heavy rainfall throughout the year. Thus, the country is prone to several natural disasters, and floods, landslides, high winds and droughts are the main events. Frequency of occurrence of such disaster events has been increasing in the recent past, where landslides have been the most deadly natural disaster in the country as far as lives and property losses are concerned. Thus there are various projects and programs being implemented for landslide risk reduction by the National Building Research Organisation (NBRO); who is the focal point for landslide risk management in Sri Lanka. Key activities could be cited as hazard mapping, early warning, structural mitigation, resettlement of families at high risk and regulating new development activities in landslide prone areas. Among such risk reduction measures, structural mitigations are mainly being proposed to reduce the landslide risk associated with strategic locations, such as; town centres, roads, rails, or critical infrastructure such as schools and hospitals etc. Implementation of structural mitigation measures are associated with expensive engineering interventions, where the recovery aspect of the investment should have been considered utilizing such mitigated locations for a productive socio-economic purpose. However, most of such strategic locations remain as under-utilised locations, after landslide risk has been mitigated. Further, there is no consideration to look at even proposed mitigations in a development perspective that focuses on long term benefits to the society.

Accordingly, this research paper attempts to look at several locations, where landslide risk has been already mitigated or either where it has been proposed to implement mitigation measures in a broader development perspective which would provide more socio-economic benefits to the society making the expenditure for landslide risk

mitigation as an investment for development. Four mitigation locations were selected for the case study namely Peradeniya town centre, Nivithigala town, Ohiya railway station and Kadugannawa.

Keywords: Landslides, Mitigation Measures, Structural Mitigation, Development Potentials

1. Introduction

1.1. Background

Occurrence of landslides, slope failures and rock falls have become a frequent natural phenomenon in the hill country causing severe damage to life and property. Out of the whole land extent of Sri Lanka, nearly 30% of the land area has been identified as landslide prone. Recent data show a sudden increase in the occurrence of landslides during the period from 2003 to 2020 in the landslide history of Sri Lanka. Major landslides occurred during the last decades including; Kotapola in 2003, Hanguranketha and Walapane in 2007, Galahawatta in 2011, Meeriyabedda in 2014, Aranayaka in 2016, Kaluthara and Rathnapura in 2017, 2019 and 2020 had proven that the sequence of landslide disaster has been gradually narrowing.

Occurrences of landslide disasters in urban or semi urban environments have a greater impact on human lives and economy as concentration of socio-economic related activities and infrastructure is dense. Economical losses of landslide disasters sometimes equal or exceed the gross national products in most developing countries (Sassa et al, 2005). The Government of Sri Lanka (GoSL) released around LKR 1000 million for emergency relief, clearing of interrupted roads and main infrastructure and logistics during landslide hazard incidents that happened in May 2017 (UNDP, 2017). Further, GoSL is implementing a resettlement program to resettle families identified as living in areas with high risk of landslides in safer areas, where the approximate cost will be about LKR 24 Billion. In this context, the GoSL has recognized the importance of the landslide hazard risk management to protect lives and properties and also to lessen the recurrent expenditures in the long run.

National Building Research Organisation (NBRO) as the focal point for landslide risk management, several projects and programs have been initiated aiming at reducing landslide risk. Such key activities could be cited as hazard mapping, early warning, structural mitigation, resettlement of families at high risk and regulating new development activities in landslide prone areas. Among such risk reduction measures, structural mitigations are mainly being proposed to reduce the landslide risk associated with strategic locations, such as town centres, roads, railways, or critical infrastructure, such as schools and hospitals...etc. Implementation of structural mitigation measures are associated with expensive engineering interventions, where the recovery aspect of the investment should have been considered utilizing such mitigated locations to a productive socio-economic purpose. However, most of such strategic locations remain as underutilised locations, after landslide risk has been mitigated. Further, there is no consideration to look at even proposed mitigation in development perspectives that focus on long term benefits to the society.

1.2. Research Problem

Over the last decade, several landslide risk mitigation projects have been implemented by the GoSL under the technical support of the NBRO and, as well as, several other mitigation projects are being implemented under different funding sources. Such key projects are Technical Cooperation for Landslide Mitigation Project (TCLMP), Climate Resilience Improvement Project (CRIP), Road Landslide Mitigation Project and Reduction of Landslide Vulnerabilities by Mitigation Measures Project (RLVMMP). The prime focus of such landslide mitigation projects has been to mitigate the risk of landslide occurrence. Although the primary objective of reducing the landslide hazard impact was achieved, there are development opportunities that would help to improve the social, environmental and economic development of the area, if landslide mitigation has been planned incorporating integrated development concerns collaboratively with planning related agencies. But, it has been found that there is no attention to harness the development potential associated with these locations during the planning stage of such projects, which would give return on investment and deliver socio-economic benefits to society beyond reduction of landslide risk.

Thus this paper attempts to emphasize development potential associated with few landslide hazards mitigated or proposed for mitigation to promote integrated landslide risk mitigation with development perspectives.

2. Literature Review

The main significance of the landslide hazard management and mitigation has been largely identified due to adverse impacts to human lives and properties. To protect life and properties from landslides and to ensure normal day-to-day activities several measures have been implemented in terms of structural and non-structural mitigation measures (Sugathapala & Prasanna, 2012). Landslide remedial measures can be arranged in four practical groups, namely: modification of slope geometry, drainage, retaining structures and internal slope reinforcement (Popescu, 2001). Also under the non – structural mitigation measures early warning systems, land use zoning, awareness programmes, creation of guidelines and regulations for steep slopes developed and cultivation of special vegetation such as grass, bamboo, etc. on unstable slopes have been implemented. (Sugathapala & Prasanna, 2012).

The cost of non-structural remedial measures is considerably low when compared with the cost of structural solutions. However, when properly designed and constructed, these structural solutions can be extremely valuable, especially in areas with high loss potential or in restricted sites (Popescu, 2001). According to Galve and others (2016), decisions for managing landslide risk are often made just taking into account the available budget. Analysis of the economic suitability or even optimization of the proposed mitigation measures are generally not considered. Therefore, they suggested using the cost benefit analysis for the estimation of costs generated by landslides and the economic losses saved due to the implementation of specific mitigation measures, in order to select suitable mitigation measures. The performed analysis done by them has shown that the most cost-effective measure to stabilize the slopes in the study area is reforesting. But, the issue here is they have not considered the direct and indirect value of incorporating development potentials in the area together with landslide mitigation measures.

In any method used to measure the performance of mitigation programs, performance should recognize as many impacts as feasible, and include the best data available from as many of those involved as possible. Benefit cost analysis, and its variants of cost-effectiveness and cost-utility analysis, apply theory-based methods to determine the value of a mitigation program across a wide range of elements of society, from individuals to groups and organizations as well as society as a whole (Ganderton, 2005). Cost-benefit and related project appraisal approaches have been applied to the 147 landslide mitigation locations in Sri Lanka under the RLVMMP project in seeking to prioritise most suitable locations for mitigation (Kumarasiri, et al., 2018). This study suggested inclusion of two more indicators in Cost-Benefit analysis to gain the highest return from the project as; 1). Maintenance cost of the mitigation sites, 2). Integrating development activities with mitigation sites (Kumarasiri, et al., 2018). In this research, it was realized that integrating development activities with the mitigation site will be added as an additional benefit to the site.

Hung (2021) has studied the public perceptions of landslide mitigation countermeasures on engineering measures. Though it has covered the confidence and usefulness of engineering mitigation measures, there is no any consideration on public perception of the development opportunities with mitigation. So far, many international researchers studied landslide mitigation measures, structural mitigation measures, and public perception on hazard and structural and non-structural countermeasures, but none of them focused on identifying the importance of development perspective of landslide mitigation measures, especially to guide the post landslide mitigation redevelopment of the particular location.

Sugathapala & Rathnasiri (2012) conducted a study in Peradeniya town, Sri Lanka to formulate a development plan to implement as a post landslide mitigation re-development strategy. In this study, human settlements investigations have been carried out considering multidisciplinary aspects of land; physical, social, economic and environment. Finally, a development plan has been prepared consulting different stakeholders and thereafter, an implementation mechanism has been formulated sharing the responsibilities between respective institutions and organizations. Though it has been prepared as a comprehensive development plan in line with proposed landslide mitigation, only the landslide mitigation works have been implemented and the development plan has remained unimplemented. At present, the mitigation site is covered with scrubs and left without any particular use though the site is located in a strategic town centre, where land value is extremely high.

Based on the literature it is found that there is not much research conducted to study the development potential associated with landslide mitigation projects and although there were few studies focused on planning perspectives, these have not been implemented on the ground level. To bridge this gap, this paper is focused to recognise the development potential associated with landslide mitigation in Sri Lanka, while referring to a few mitigation projects.

3. Case Study and Methodology

3.1. Study area

Three Landslide mitigation locations were selected for this study; 01) Peradeniya Town Centre where the site is located in Kandy District and the landslide mitigation works were completed during the 2010 - 2012 period; 02) Nivithigala town where the site is located Ratnapura District and selected for mitigation under the RLVMMP project and the construction works have already commenced; and 03) Ohiya railway station where the site is located in Badulla District and selected for mitigation under the RLVMMP project.

3.2. Method of data collection

The method of data collection consists of collection of secondary data through literature and primary data through field investigations and stakeholder & public consultation.

- Field investigations - to identify the development potentials associated with mitigation measures, local and regional connectivity and social and economic activities of the area.

- Public consultation - to identify their perception on development potentials/ activities along a time cycle.

- Stakeholder and partner consultation - to identify their perception on development potentials, gaps and limitations to include planning perspectives and implement development potentials.

Descriptive qualitative method and comparative method have been used for data analysis.

4. Results and Findings

4.1. Development potentials of landslide mitigation locations

Field observations and investigations were conducted in each mitigation location to identify the development potentials which can be syndicated with mitigation measures. Each location had unique characteristics when compared with others and accordingly following development potentials associated with each location were identified through the field observations and socio-economic surveys.

Peradeniya Town Centre

The potential of the Peradeniya town to further develop with the protection of the town from the landslide threat was identified. Specially, four major operations of the Peradeniya town were identified through socioeconomic surveys. Four operations were: transition centre; market centre; livelihood for surrounding communities; and gate way to the City of Kandy. Currently, most of the buildings located in the town center are obsolete physically, where regeneration is required. Thus, land liberated from landslide risk mitigation; which is located right at the middle of the town center, could be used effectively to promote people centred and nature friendly built environment.

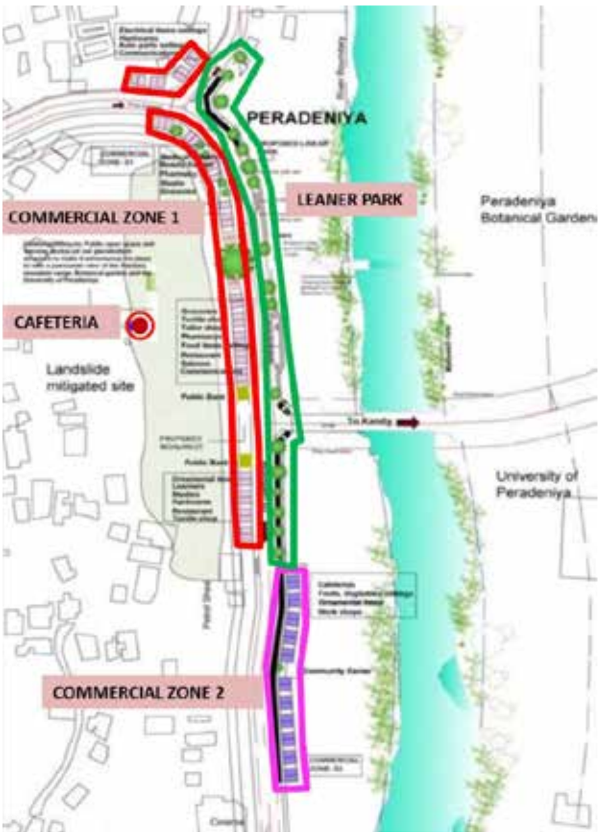


Figure 01 : Proposed Peradeniya Development Plan

Accordingly, it was proposed to develop a commercial complex (commercial zone 1) on the landslide mitigated land, relocating commercial establishments that are located along the river bank. Then, the river bank was proposed to be converted as a linear park considering the surrounding natural settings, making connection between pedestrians, town centre and surrounding developments. This proposals have been accepted by all the stakeholders including users of the town (Sugathapala & Rathnasiri, 2012).

Nivithigala Town Centre

The site is located along the Thiriwanaketiya – Agalawatta Road which is connecting major cities; Agalawatta in Kaluthara District and Thiriwanaketiya and Ratnapura in Ratnapura District. Hence, most local and foreign tourists are travelling via Nivithigala town frequently. It could be identified that the Nivithigala town is functioning well since there is a vast catchment area to the city; around 10 km radius from the city. Therefore, a considerable amount of people are travelling daily to fulfil their requirements. Further, Nivithigala area is well prominent for the gem industry and therefore, an informal market had been formed in the town centre for gem business with numerous buyers and sellers.

Accordingly, based on the development potentials, the proposed action plan was mainly focused on providing facilities to gem businessmen with adequate space and building in the area liberated with the implementation of landslide mitigation. Thus, it is expected to minimize the traffic congestion in the town centre where gem businesses currently operate. Further, providing open spaces, relaxation areas, market places and viewing decks for travellers, which would generate considerable socio-economic benefits in the local context.

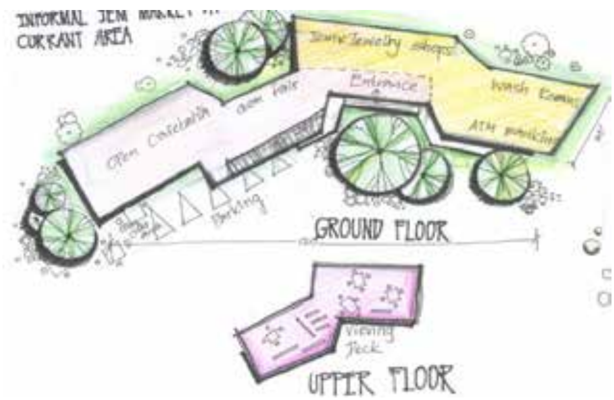


Figure 02 : Layout Plan - Proposed Nivithigala Development Plan

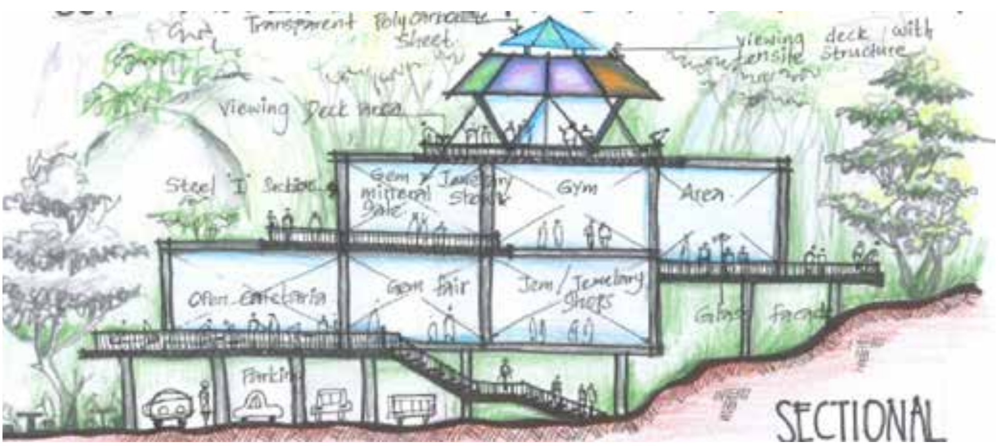


Figure 03 : Cross Section - Proposed Nivithigala Development Plan

Ohiya Railway Station

Ohiya railway station is located at a tourist destination. There are many prominent tourism hot spots surrounding the station. Therefore, many local and foreign tourists hang around and pass through this area. Station master revealed that about 100 -150 passengers use the Ohiya station on a daily basis. Of those passengers more than 75% are tourists. Hence, development of this area as a tourist centre along with the landslide risk reduction would provide more socioeconomic benefits to the society and to local and foreign tourists as well.

Figure 04 : Proposed Ohiya Station Development Plan

By understanding the development potentials of the area, proposed Ohiya Square Development mainly focuses on a parking area, semi-open area with waiting area, relaxing area and changing room for local and foreign tourists, gardening area with nature based landslide mitigations and observation deck.

5. Conclusion and Recommendations

This paper attempted to emphasize the development potentials associated with locations selected for landslide risk mitigation, where adequate attention to harness such potential has not been paid. Specially, developing countries like Sri Lanka are spending considerable amounts of public money for disaster risk mitigation. However, if such mitigation had been properly planned under a broader development perspective, more socio-economic benefits would have been generated making the expenditure for mitigation as an investment for the development.

Wider stakeholder consultation at the planning stage of the mitigation project should be undertaken that includes the participation of planning related agencies, administrators and local community to understand the significance of a particular location in national, regional and local context, and thereby, to understand the development potentials associated with the specific location. Thus, implementation plans and funding plans could be discussed and agreed among the line agencies under their purviews and mandates promoting an integrated development approach.

6. References

1. Galve, J. P., Cevasco, A., Brandolini, P., Piacentini, D., Azañón, J. M., Notti, D., & Soldati, M. (2016). Cost-based analysis of mitigation measures for shallow-landslide risk reduction strategies. Engineering Geology 213, 142–157.
2. Ganderton, P. (2005). 'Benefit–Cost Analysis' Of Disaster Mitigation: Application As a Policy And Decision-Making Tool. Mitigation and Adaptation Strategies for Global Change.
3. Huang, H., Huang, J., Liu, D., & He, Z. (2021). Understanding the public responses to landslide countermeasures in southwest China. International Journal of Disaster Risk Reduction 64 (2021) 102500.
4. Kumarasiri, C. W., Prasanna, L. J., Jayaprakash, S., Indrathilake, H. M., Sugathapala, K. C., & Bandara, R. S. (2018). Cost-Benefit Analysis for the Mitigation Measures of Landslide Vulnerability Reduction. Proceeding of 9th Annual NBRO Symposium "Innavaion for Built Back Better" (pp. 299-308). Colombo. Sri Lanka: National Building Research Organisation.
5. Mandasaria, J., Arifina, M., & Alia, M. (2016). Settlement arrangement based on landslide mitigation (Case study: Capagallung, west Bacukiki District, City of Parepare). Social and Behavioral Sciences 227 (pp. 442 – 450). Surabaya, Indonesia: International Conference, Intelligent Planning Towards Smart Cities, CITIES 2015.
6. Ministry of Disaster Management. (2017). Sri Lanka Rapid Post Disaster Needs Assessment Floods and Landslides, May 2017. Colombo: Ministry of Disaster Management & Ministry of National Policy and Economic Affairs in collaboration with the United Nations, World Bank and European Union.
7. National Building Research Organisation. (2018-2021). Environmental and Social Management Framework. Colombo: Reduction of Landslide Vulnerabilities by Mitigation Measures Project (RLVMMP).
8. Popescu, M. E., & Sasahara, K. (2009). Engineering Measures for Landslide Disaster Mitigation.
9. Sugathapala, K., & Prasanna, J. (2009). Issues in Implementation of Landslide Mitigation Programmes in Landslide Vulnerable areas of Sri Lanka: Special Reference to Hanguranketha Landslide area. NBRO National Symposium. Colombo: National Building Research Organisation.
10. Sugathapala, K., & Rathnasiri, C. (2012). Mitigation and Redevelopment as a Sustainable Development Strategy for Disaster Prone Human Settlements: With special reference to Landslide at Peradeniya Town. ACEPS, 266-271.

Geotechnical Clearance for Sub-structure Constructions Ensuring the Resilience of New Developments in Urban Areas

TRST Wijewardhana[1], TAS Sandeepani [1], GRY Perera[1]

[1]Scientist, National Building Research Organisation, Sri lanka

Abstract

As a result of the shortage of land due to factors like industrialization, population growth, and urbanization, the construction of high-rise buildings has increased. The majority of newly constructed structures have excavations for big basements and pile foundations. Sometimes, such construction exerts negative influence on surrounding structures and this has been found to be intensified by recent developments. Poor foundation systems of existing structures are also one of the main reasons for their collapse. Most project approving agencies are seeking the assistance of consultants such as National Building Research Organisation (NBRO) to assist with the geotechnical clearance procedures in order to address this issue. Though there are several mitigatory measures available, it still remains as a doubt how well those measures can resist adverse impacts related to the adjacent structures. Therefore, it is important to analyze carefully about the available problems and provide practical solutions that can be carried out in the site itself in an efficient and effective manner. Identifying the characteristics of the existing adjacent structures plays a major role apart from the major mitigatory measures like, shoring systems, controlled dewatering systems, advanced foundation construction, damping of the vibration impacts and proper workmanship. This study mainly focuses on the adverse impacts on adjacent structures due to new developments and the methodologies for ensuring the resilience of new developments through the clearance process developed to prevent such situations.

Keywords: New Developments, Adjacent Structures, Foundation Systems, Adverse Impact, Resilience, Clearance Process

1. Introduction

High-rise building construction has been steadily increasing around the world as a result of population growth, urbanization and industrialization. Due to shortage in buildable land, the construction of high-rise buildings has become common in Sri Lanka, particularly in the Capital City and in other urban areas. Deep excavations, the use of heavy equipment such as boring machines and dewatering have all become key challenges when considering the impact of new developments on adjacent structures. The involvement of professional bodies such as the National Building Research Organisation (NBRO), the Urban Development Authority (UDA) and the Central Environmental Authority (CEA) plays a key role in ensuring the resilience of new developments through the clearance process developed to prevent such situations.

The main causes of unfavourable impacts to nearby structures are deep excavations, piling, shoring, dewatering, and vibration produced by construction work. Furthermore, the state of existing structures has a significant effect on the stability of such structures. The development of high-rise structures causes the largest impact on adjacent buildings with shallow foundations. Conducting a pre-construction survey can be identified as the most suitable way to assess existing features and structural stability issues of adjacent structures. When there is a demolition of any building or piling or foundation works, tunnelling works or site formation works (including excavation works), the builder shall, before commencing such works, carry out a pre- construction survey to establish the condition of existing buildings and structures adjacent or otherwise in close proximity to the building works (Wijewardana, 2018).

Table 01: Classification of the impacts (Wijewardana, 2018)

Construction induced impacts on adjacent structures	Impacts of existing structures
Type of construction equipment used and vibrations induced from machinery.	Foundation settlement
Method of construction - deep excavations, pilling, diaphragm walls etc.	Issues with the usage of poor construction materials
Excessive or uncontrolled dewatering/ (without close monitoring and observation).	Poor workmanship
Changes in ground conditions (soil +rock)	Uneven stress distribution
Ground movements (vertical - settlement & heaving & lateral)	Thermal expansions
Movement of shoring systems	Inadequate structural requirements
Ground subsidence due to dewatering	Excessive loads
Movement of finer soil particles with seepage water creating voids	Natural disasters (adverse impacts due to landslides, floods and high winds)
Heaving (upward movement) of the ground	

Close monitoring of the Table 1, it is illustrating that differentiate undergoing long term settlements and defects for the adjacent structures are due to the newly constructed buildings. In this study, it is focused on adjacent construction induced impacts on existing structures and the problem in the existing structures.

2. Identifying the problem

Rapid development of Country's economy has resulted in the construction of new buildings in Sri Lanka. Due to the scarcity of land in urban areas, the newly constructed structures are often surrounded by other existing buildings. Hence, many adjacent structures in the past few years became affected by the development of high-rise buildings. With the rapid increase in construction works in congested environments, possibility of safely extending the life of existing infrastructure is a matter that has become of increasing importance to the work of structural engineers. In order to understand safety of the structure, it requires prediction of future structural behavior in detail and at a high accuracy level. So that, proper initial assessment of the existing structure can be identified as the best mechanism to mitigate subsequent impacts. Fortunately, Sri Lanka so far escaped from devastative large building collapse disasters. During the last couple of years, the country experienced only a few minor building collapses which occurred due to poor construction practices and associated loopholes in the approval process. (Weerasekara TD, Wijewardana TRST, & Jayathilake D, 2019). This is due to the construction of structures with lack of standard methodologies, absence of monitoring and improper planning of contingencies. During the sub structure works, majority of the structures are designed without taking into account the required geotechnical characteristics and precautions. Following the recent collapses of buildings and sinking of properties, it was determined that suitable evaluation and clearance procedures are required to safeguard the safety of neighbouring properties.

2.1. Sources of construction induced impacts

2.1.1. Demolition of existing structures

Demolition is the process whereby an existing building is destroyed partly or completely and is usually carried out on a temporary/short term basis. Demolition is carried out either manually or mechanically using large hydraulic equipment such as elevated work platforms, hammers, cranes, excavators or bulldozers. Larger buildings however may require the use of a wrecking ball or are destroyed by implosion. Newer methods may use rotational hydraulic shears and silenced rock-breakers attached to excavators to cut or break through wood, steel and concrete. Demolition of buildings is associated with environmental concerns which relate to noise and vibration, dust nuisance, solid wastes including waste debris, hazardous wastes and larger energy or water consumption (Environmental Guideline on Demolition of buildings, 2017).

2.1.2. Excavations

New large scale mid-rise and high-rise buildings in urban neighborhoods often require foundation structures 1 to 5 stories deep to accommodate underground parking decks and building mechanical systems. These new foundation systems are often much deeper than the foundations of previous structures as well as those of neighboring properties. As a result, construction activities require the excavation of deep pits, often with vertical faces. Damage to adjacent properties can result throughout this process from inadequately shored excavation walls or from vibrations due to demolition, excavation or pile driving activities.

Since most excavations in an urban setting occur on or near the property lines and flattened slopes (less than 45 degrees of vertical) are typically incompatible with design requirements, many applications require a temporary reinforced wall be constructed to retain soil and buildings on the neighboring lots (Smith, Vatovec, & Gumpertz, 2015).

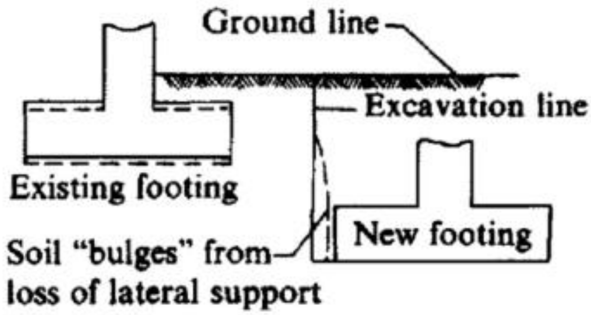


Figure 01: The Possible settlement for existing foundation due to the lack of suitable retaining wall

2.1.3. Blasting and Vibrations

Vibration can occur from numerous construction activities, including; Blasting, Pile driving, Compaction/dynamic compaction, Jackhammering/chiseling, Pavement breakers, demolition, trenching activities, heavy vehicle movements.

Pile driving vibrations may affect the nearby structures or disturbed people in the neighbourhood of pile driving activity. Some previous literature results show that vibration effect was higher at the bottom of a building compared to the effect on the top of building. Also, the nearer distance cause higher vibrations compared to the one further from the building. However, the smaller pile creates more vibrations towards the nearby building. This could be due to pile density reaction towards resisting forces from soil (Musir & Ghani, 2014).

2.1.4. Drawdown of the water table

Due to improper excavations and improper dewatering practices, there can be problematic drawdown in the exiting ground water table. This can cause serious damages to the soil profile and existing nearby structures due to settlements in the soil profile.

Apart from the above discussed sources improper workmanships can be also identified as a major factor that cause damaging impacts for adjacent structures.

3. Preventive measures

3.1. Pre-construction surveys

Conducting a pre-construction survey can be identified as the most suitable way to assess existing features and structural issues of adjacent structures. When there is a demolition of any building or piling or foundation works, tunnelling works or site formation works (including excavation works) are to be carried out, the builder shall, before commencing such works, carry out a pre-construction survey to establish the condition of existing buildings and structures adjacent or in otherwise close proximity to the building works. Then it is logical to differentiate between exiting structural issues and structural issues that can arise due to the adjacent construction, so that at the initial stage, relevant preventive measures and rectifications can be implemented. It is the responsibility of the adjacent residents to conduct a pre-construction survey or allow/ help developers and contractors to conduct the survey by providing them necessary information. In the event that the developer is unable to gain entry to the properties in the zone of preconstruction survey, the developer shall, survey the exterior face of the property, keep records of attempts to contact relevant owners for permission to conduct pre-construction survey and keep record of refusal by the adjacent owner to allow access to conduct survey. (Smith, Vatovec & Gumpertz, 2015)

Following sub-sections outline the minimum zones of pre-construction survey to be conducted for project developments involving demolition, piling and excavation works. Photographic surveys and data collection methods shall be adopted after identifying the relevant effective areas in order to collect the necessary information regarding the existing structures. However, qualified professionals in charge of each project shall implement an independent assessment and verification to determine an adequate and sufficient criterion depending the nature of the project and the construction site. (Guidelines on Preconstruction Survey, 2016)

3.1.1. Demolition works

Table 02: Suggested pre-construction area before commencing any Demolition Works (Guidelines on Preconstruction Survey, 2016)

Type of Development	Minimum zone of pre-construction survey (from the edge of building to be demolished)
Demolition for landed development	10 m
Demolition for building up to 5 storey height	35 m
Demolition for building more than 5 storey height	50 m

3.1.2. Pilling works

Table 03: Suggested pre-construction area before commencing any piling work in *landed development (Guidelines on Preconstruction Survey, 2016)

Type of Piles	Minimum zone of pre-construction survey
Non-displacement piles and small displacement piles such as micro bored pile, steel H-piles	10 m
Displacement piles such as RC piles, jacked-in steel pipe piles (closed ended)	20 m

Table 04: Suggested pre-construction area before commencing any piling work in *non-landed development (Guidelines on Preconstruction Survey, 2016)

Type of Piles	Minimum zone of pre-construction survey
Non-displacement piles and small displacement piles such as micro bored pile, steel H-piles	40 m
Displacement piles such as RC piles, jacked-in steel pipe piles (closed ended)	60 m

* Landed development refers to residential property where the owner has the title to the land. Non-landed property refers to apartments and condominiums, which are strata-titled, where the owners own the land in common.

3.1.3. Excavation works

Table 05: Suggested pre-construction area before commencing any Excavation works (Guidelines on Preconstruction Survey, 2016)

<table>
<tr><th>Type of Development</th><th colspan="2">Minimum zone of pre-construction survey</th></tr>
<tr><td>Landed development</td><td colspan="2">15 m</td></tr>
<tr><td>Displacement piles such as RC piles, jacked-in steel pipe piles (closed ended)</td><td colspan="2">60 m</td></tr>
<tr><td rowspan="4">Non-landed development with basement or underground space</td><td>Type of Soils</td><td>Minimum zone of pre-construction survey</td></tr>
<tr><td>Good soils</td><td>30 m or 3H</td></tr>
<tr><td>Soft soils (e.g. marine clay) Without fluvial/sand/peat/peaty clay</td><td>60m or 6H</td></tr>
<tr><td>Soft soils with fluvial/sand/peat/peaty clay</td><td>90m or 9H</td></tr>
<tr><td colspan="3">Note:
1. Maximum excavation depth include localise pits;
2. For cases with two values, the larger of the two values should be adopted.
3. *Good soils refer to medium dense to very dense sand and gravel, and firm to hard silt and clay.
4. *Soft soils refer to very loose to loose sand and gravel, and very soft to soft silt and clay.
5. *H is defined as the maximum excavation depth.</td></tr>
</table>

3.2. Shoring systems

While there are numerous temporary methods available to retain soil for an excavation, the soldier pile wall with tiebacks and wood lagging is the most common. Tie back soldier pile walls are constructed with wide flange steel beams, usually spaced 5 to 10 feet apart. The walls can be 50 feet in height or greater from the top of existing grade to the bottom of the trench. Tiebacks are installed integrally aligned with the soldier pile. The space in between the soldier piles is constructed with thick wood planks inserted between flanges of the piles and span from soldier pile to soldier pile to retain the soil. Ground water cannot be tolerated and must be removed based on requirements set forth in geotechnical and sub-surface hydrology reports. However, for larger basement constructions and deep excavations most of contractors have used diaphragm walls which will also act as a permanent element of the structure after the completion of the project. (Volonnino. 2017)

3.3. Proper dewatering system

Having clearly identified the sub-surface profile and excavation details, required number of open sumps and observation wells should be designed with the use of submersible pumps and other required instruments that fulfill the required flowrates and capacities. Before commencing pumping, it is important to measure the water levels in all the wells. Throughout the dewatering process, deformation monitoring of the adjacent structures and ground water level monitoring should be continued. If monitoring records indicate a significant drawdown of the water table, observational wells shall be used for recharging of the ground water level.

3.4. Damping vibration impacts

Permanent vibration barriers are effective for controlling long term vibrations such as traffic induced vibrations. In such a case permanent wave barrier can be used which is filled with a vibration damping waste material. However, in the case of piling induced vibration, it is a short-term vibration. Therefore, it is effective and economical to go for short term vibration controlling methods.

When considering about the research related effective control methods throughout the past decade, trench system can be identified as the best and effective control method. However, the applicability of a trench in modern day construction sites may cause several additional problems due to the insufficient land spaces. Another major control method available can be identified as damping the vibrations at the source. In order to fulfil that requirement, highly developed vibration damping machineries have to be used for the construction activities which also cost more investments.

3.5. Implementation of proper workmanship

There will be no use of the mitigatory measures if the quality and the workmanship of the work fails. Careful planning and sequencing of the construction from the most initial level of the project gives numerous advantages. Geotechnical site investigation stage can be identified as one of the most critical stages when considering about impacts on adjacent structures. Effective site investigation techniques shall be carried out by relevant professionals who are specialized in that field in order to obtain the most effective and accurate recommendations for important design criteria like foundation type, shoring type and details about the existing water table. After identifying the most relevant structural design requirements, each and every construction activity shall be carried out by following the method statements and specifications given by qualified engineers. Usage of quality construction materials will further enhance the quality of the workmanship. There should be a close monitoring and data collection procedure for the ground water table, vibration levels and any movement or failure of shoring systems so that the records can be used when implementing preventive measures.

4. Involvement of professional consultants

It will take adequate designing, planning, evaluation, and engineering solutions to minimize the adverse impact to the adjacent building when constructing a high rise building. As a result, Project Approving Agencies (PAAs) such as the Urban Development Authority (UDA), the Sri Lanka Tourism Development Authority (SLTDA), and the Department of Coast Conservation and Coastal Resource Management (CCD) request the National Building Research Organisation (NBRO) be involved in the geotechnical clearance process for the impact on adjacent structures. In this regard, it is recommended with the assistance of the National Building Research Organisation, to assess the condition of existing buildings adjacent to the new construction, evaluate the design of the new building, and proceed with the monitoring and contingency plans for the special building categories in Sri Lanka. The National Building Research Organisation's procedure for obtaining clearance for high-rise projects is depicted in Figure 2.

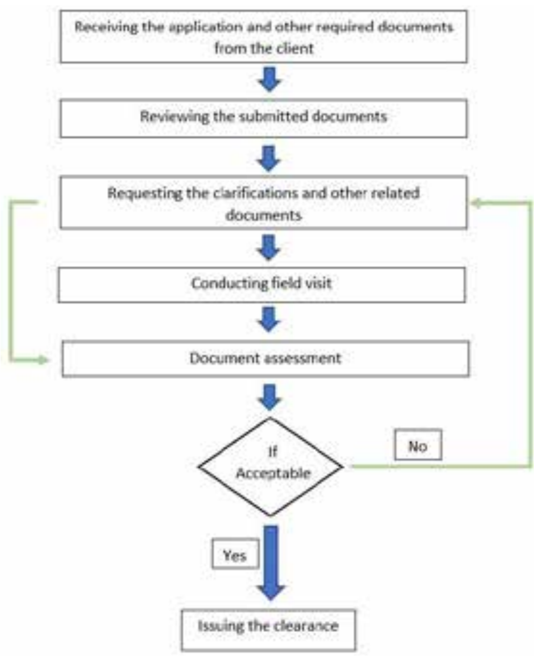


Figure 02: Procedure of the Geotechnical Clearance Process

5. Case study to understand the practical site issues and role of NBRO

The project named Galle Face Icon formerly known as Renuka Tower is located at Colombo - 03 in between Galle Face Green and Beira Lake. It is a 32-level mixed development with a total building area of 200,000 sqft and 4 basement levels. The tower is consisting of grade A premium office space, service suites, office amenities, more than 200 parking slots. Tower also has corporate conference facilities, recreational area and safer working environment with modern facilities. The total cost of the project was estimated as Rs. 1.03 billion. National Gem & Jewellery Authority which is having a shallow foundation is one of the adjacent buildings located near the above proposed project.

A competent shoring system and an excavation supporting system were required for the newly constructed structure, which was built on a pile foundation. As the excavation's supporting structure, a secant pile wall was used.

Figure 03: Site Location

The National Gem and Jewellery Authority made a complaint with the National Building Research Organisation over damage to their building caused by a nearby active project. In response to the complaint, the NBRO advised the developer to halt construction and submit the necessary documentation in order to issue building approval for the new development. A provisional clearance for twelve months was granted with mandatory recommendations to follow out based on the developer's documents and the site visit conducted by NBRO officials. Further, it was recommended to carry out a proper monitoring plan with inclinometer and piezometer readings and a contingency plan to rectify the damages to the NGJA building. The frequency of inclinometer readings is one time per day and piezometer readings is four times per day.

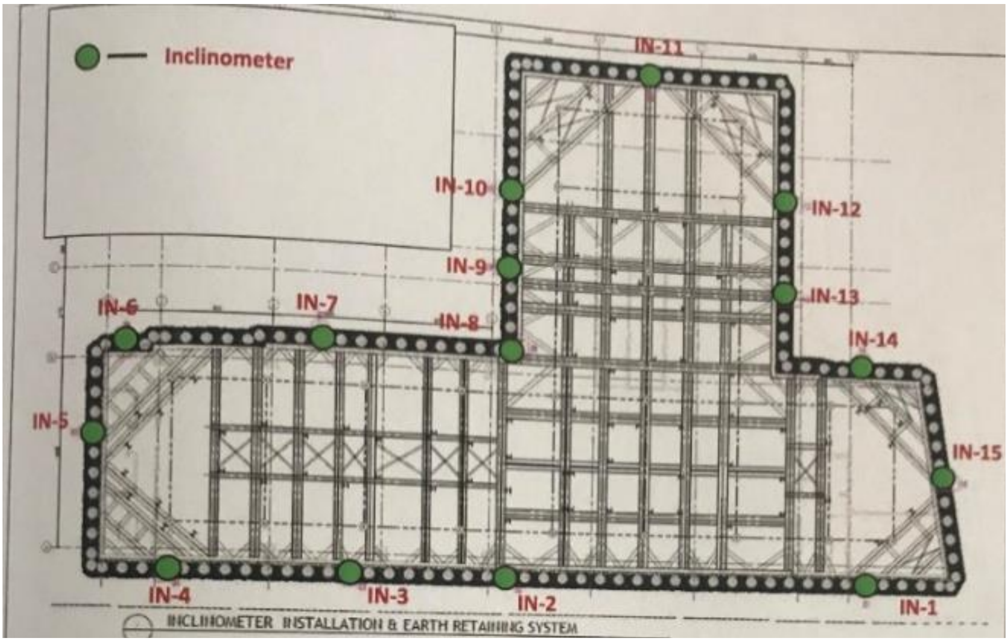


Figure 04: The locations of inclinometers installed around the newly constructed structure

During the construction works, a leakage originated through the secant pile wall. The cracks were induced in the National Gem & Jewellery Authority building and it started to settle. Even though, there was a monitoring procedure, the leakage could not be identified before it originated. After that incident, by means of a resistivity survey, it was identified that large horizontally elongated cavities with the approximately depth of 20 - 30 cm were formed within first 5 m to 6 m depth from the existing ground level in the National Gem & Jewellery Authority land. Thereafter, it was confirmed by conducting a borehole test. Even though the water leakage was induced 15 m below the ground level, it was discovered that soil has been loosened in first 6m depth from the ground level. One of the main reasons for the adverse impact to the National Gem & Jewellery Authority building is having a weak foundation on the building itself.

6. Discussion

The foundation system of most of the existing buildings in Sri Lanka is weaker than the foundations of newly constructed buildings as in the case study discussed. Therefore, it is essential to assess and investigate the foundation system of the adjacent structures before commencing a new construction with deep excavations. Further research activities have to be carried out in order to identify specific impacts of adjacent building construction works to match with the Sri Lankan construction context (Wijewardana, 2018).

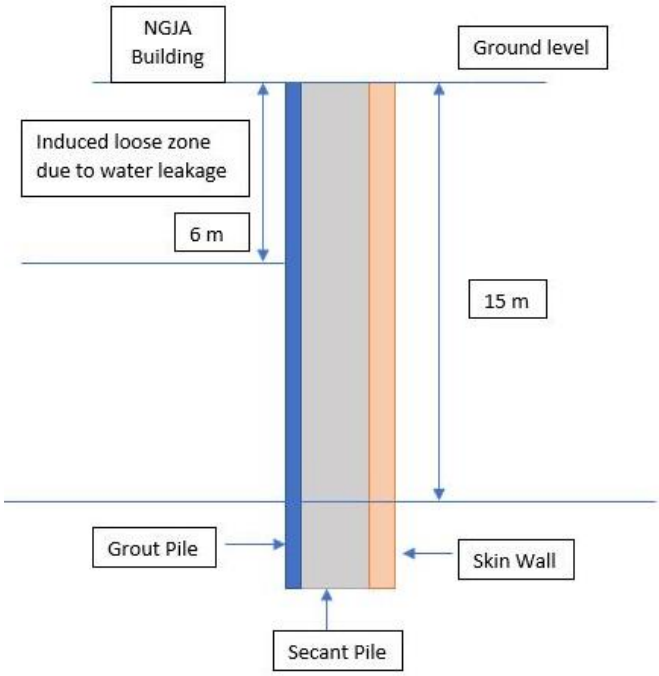


Figure 05: Cross section of the design

According to the case study mentioned, the recommendations given by the NBRO was to perform actions to stop the soil particle leakage and the water leakage through the secant pile wall. This was done to minimize the soil collapsing and to prevent the further impacts to the building. In order to block the water and particle seepage, firstly it was advised to construct a grout pile protection wall outside of the excavated area. And then to construct the skin wall in the side of excavation. It was recommended to design grout piles and the skin wall according to the standards of water retaining structures. Finally, it was instructed to the contractor to develop a proper foundation for the NGJA building in order to stabilize the building. The figure 4 represents the cross section of the design in order to prevent the water seepage.

Furthermore, an accurate and extensive geotechnical investigation should be carried out prior to the construction work in order to get a comprehensive knowledge about the soil condition, adjacent structures and to design a proper foundation system. This will result in minimizing the adverse impact on the construction as well as on the adjacent structures.

According to the case study discussed, it depicts the importance of the proper identification of the condition of the adjacent structures in order to minimize future problems. It is necessary to pay more attention on structural and geotechnical aspects rather than merely focusing on planning aspects. Furthermore, identification of characteristics of the existing adjacent structures has to be carried out by giving a prior consideration in order to overcome future problematic impacts. Regular monitoring of the impact assessments shall be conducted by considering the major construction activities like excavations, excavation support systems, dewatering and pile boring. Each and every construction activity shall be implemented with the close supervision of qualified engineers and following the method statements for relevant activities.

Further research activities have to be carried out in order to identify the specific impacts on adjacent building construction works to match with the Sri Lankan construction context. Relevant solutions needed to be identified by carefully analyzing those impact parameters so that the implementation of the mitigatory measures give more effective and efficient results by ensuring the resilience of new developments in Sri Lanka.

7. References

1. Weerasekara T. D, Wijewardana T. R. S. T, & Jayathilake D. (2019). Challenges faced on Geotechnical Assessment Process on Adjacent Structures. *10th Annual Symposium, National Building Research Organisation.*
2. Wijewardana T. R. S. T. (2018). Adverse impacts of new construction projects on adjacent structures and implementation of mitigatory measures. *9th Annual Symposium, National Building Research Organisation.*
3. Smith, N., Vatovec, M., & Gumpertz, S. (2015). *Mitigating and Remediating Damage to Properties Adjacent to Construction in Congested Urban Environments.* ICRI Spring Convention.
4. *Guidelines on Preconstruction Survey*. Singapore: Building and Construction Authority., (2017).
5. *Environmental Guideline on Demolition of buildings*. Republic of Mauritius., (2017).
6. Smith, N., Vatovec, M., & Gumpertz, S. (2015). *Mitigating and Remediating Damage to Properties Adjacent to Construction in Congested Urban Environments.* ICRI Spring Convention.
7. Musir, A. A., & Ghani, A. N. (2014). A study of pile driving effects on nearby building. *International Journal of GEOMATE,* 806-810.
8. Volonnino, A. (2017, 08 15). Deep Excavation and Vibratory Damage. *Structural Damage from Adjacent Construction Projects.*
9. *Guidelines on Preconstruction Survey*. Singapore: Building and Construction Authority., (2017).

Landslide Risk Status Analysis of Nuwara-Eliya District - As the outcome of the Landslide Risk Profile Development Project

WKC Kumarasiri[1], Chanchala De Silva[1], SDA Jeevana[1], KC Sugathapala[2]

[1]Scientist, National Building Research Organisation, Sri Lanka
[2]Director, Human Settlements Planning & Training Division, National Building Research Organisation, Sri Lanka

Abstract

Occurrence of devastating landslides has become more frequent in Sri Lanka attracting more and more attention due to its increasing effect on human and economic losses. Landslide Risk Profile Development Project is a five-year project (2016- 2022) implemented in fourteen (14) administrative districts susceptible to landslide hazard (i.e., Badulla, Nuwara-Eliya, Kegalle, Ratnapura, Kalutara, Galle, Matara, Kandy, Matale. Hambantota, Colombo, Gampaha and Kurunagala). Outputs of this project will be given in an understandable language to decision makers in planning agencies / organizations. Further, using these landslide risk maps, decision makers could easily identify risk treatment options and issues that may arise during resettlement of the communities at risk.

Landslides could create further devastation in future due to impacts of prevailing global climate change. Hence, identification of landslide prone areas with high-risk potential and implementation of proper and effective landslide mitigation interventions to minimize the risk, have become an essential priority need. In order to make risk management programs more meaningful and cost effective these programs should target risk reduction in high-risk settlements through a comparative assessment of risk potential.

Keywords: Landslide, Exposure Map, Building Survey, Element at Risk

1. Introduction

National Building Research Organisation (NBRO) has been preparing landslide hazard zonation maps since 1992. Landslide hazard mapping in Sri Lanka may be considered as a unique experience and in this context, it is perhaps the first comprehensive attempt to generate maps of human settlements and infrastructure on 1:10,000 scales conjointly with other nature maps.

Landslide Risk Assessment and Risk Profile Development Program is implemented by National Building Research Organisation (NBRO) with the financial assistance of United Nations Development Program and Government of Sri Lanka. This project was initiated to meet the outcome - 1 of the Sri Lanka Comprehensive Disaster Management Programme (SLCDMP) 2014 - 2018. These risk profiles and risk maps prepared by NBRO will increase the capacity of national and sub-national level agencies in assessing the disaster risk and making decisions for short, medium and long-term disaster management.

Landslide hazard maps delineate areas according to the associated degree of hazard. Risk map is prepared based on hazard assessment already being prepared under Landslide Hazard Zonation Mapping Project. Risk map is meant by the zoning map that includes the possible damages to human lives and properties due to occurrence of landslide. The risk map will lead to further investigations and migratory actions which could be planned. In fact, such maps serve as a tool to guide investments in development and utilization of lands susceptible to landslides.

Therefore, NBRO has launched a project that focuses on the development risk assessment which can guide the decision makers in planning agencies such as Urban Development Authority and National Physical Planning Department.

Household survey is conducted under landslide risk mapping project, for very high and high-risk areas identified through landslide exposure map. The divisional level risk profiles are prepared using the data and information collected through this survey. The survey is carried out using four (04) types of questionnaires for households, institutions, religious places and schools. Grama Niladhari Officers of respective Grama Niladhari Divisions have surveyed 16,930 buildings in Nuwara-Eliya District.

2. Objectives

- To make aware the people in landslide prone areas on risks faced by them to take preventive measures.
- To develop "elements at risk database" that takes into consideration the characteristics and use of the buildings and the characteristics of the inhabitants.
- To take decisions regarding timely interventions before, during and after a disaster.
- To be the foundation for community risk assessment and to identify possible

short, medium and long-term risk reduction measures.

- To provide the risk information for decision making in planning and investment and thereby, minimize exposure to landslide.
- To enhance dissemination of landslide early warning.

3. Methodology

In this study, spatial distribution of vulnerable buildings located in very high and high landslide hazard area are being identified using the Landslide Hazard Zonation maps. Through the survey, maps are being prepared for the settlements located within Grama Niladhari Divisions (GNDs), the lowest administrative units , while demarcating spatial distribution of most vulnerable buildings. For this purpose, it is decided to prepare 3 types of maps with different scales to obtain a clear understanding of spatial distribution of vulnerable buildings.

There were two main challenges to overcome for successful implementation of the building survey. First challenge is to find correct spatial data of each GN boundary. It was difficult to find spatial data of some GN boundaries accurately that perfectly match with actual administrative areas. Second challenge was to make aware GN officers to read and understand spatial data (maps). Methodology of the building survey has been designed to implement the survey by overcoming these issues. The process of map preparation and questionnaire survey is explained in under this section.

4. Training of survey enumerators (Grama Niladari Officers)

The first step of the process was to conduct training for survey enumerators. One of the objectives of the training programs is to build awareness among the people in landslide prone areas on risks faced by them to take preventive measures. On other hand training was conducted to introduce exposure maps and categorization of questionnaires (households, institutions, religious places, and schools) which were used throughout the survey.

5. Verification of Grama Niladhari Boundaries

Before going to preparation of maps there were some issues raised regarding demarcation of Grama Niladhari (GN) boundaries. On the first day of introduction of maps, some Grama Niladhari officers informed the problems they find with the GN boundaries. Therefore, it was necessary first to verify GN boundaries before preparing maps. The process was re- organized and another workshop was conducted with the support of GN officers to verify the GN boundaries.

In this workshop, the GN boundaries from the Survey Department were used as the source layer in the verification. Satellite images were used to identify the correct boundaries of GN divisions. Most of these physical boundaries are laid along natural features such as streams, rivers, and forests, or either manmade features like roads. So, these feature layers were effectively used to identify the exact boundaries.

6. Preparation of Exposure Maps

After finalizing the GN boundaries, the maps were prepared for each GND. There were 4 types of maps indicating vulnerable buildings identified in the survey. First map was compiled using Landslide Hazard Zonation Map & building layers. Those maps indicate the exposure of the buildings to landslide hazard of the area.

These maps included identified vulnerable buildings based on the high hazard zones and also other data like hazard zone description, topographic data, infrastructure data etc. When ground data collection is ongoing it is difficult to identify each and every vulnerable building. For this purpose, the identified vulnerable buildings were clustered to prepare 1: 1,000 scale maps to ease the field data collection work. Clustered vulnerable buildings were indicated in a grid to have easy identification in the map. One exposure map had several grids depending on the number of vulnerable buildings and maps were separately printed with all the grids indicating grid numbers.

After identification of vulnerable building clusters, all the buildings in hazardous areas were numbered in order to refer when filling the questionnaires. The numbers were presented on the 1:1,000 scale map.

7. Distribution of maps among GN officers

The distribution of maps was carried out based on Divisional Secretariat Divisions (DSD). The GN officers of each DSD met at the office and the maps were distributed. Afterwards, GN officers were requested to start the field survey to collect the data of identified buildings.

8. Monitoring & Supervision

Field data collection was done under the direct supervision of NBRO officers. At the initial stage of data collection some GN officers had difficulties in identification of spatial distribution of buildings. Therefore, NBRO officers always provided their support for the issues those were encountered in the ground data collection.

Table 01: Number of buildings according to hazard category in Nuwara Eliya district

Number of Buildings Located on Landslide Hazard Zones						
No	Divisional Secretariat Divisions	Landslides are most likely to occur	Landslides are to be expected	Landslides have been occurred in the past	Subsidence and rock fall	Total
1	Nuwara-Eliya	-	1,400	233	-	1,633
2	Hanguranketha	137	5,166	266	74	5,643
3	Walapane	636	8,621	283	114	9,654
	Total	773	15,187	782	188	16,930

Above calculation was done based on 1:10,000 scale Landslide Hazard Zonation Map. In this survey, 4 types of hazard categories were used which are considered as high & medium hazard classes. The table presented the number of vulnerable buildings with reference to their hazard zone.

Table 2: Status summary of Building Survey at Nuwara Eliya district

No	DS Divisions	No of Buildings located	Categories of Buildings Surveyed				
			Household	Commercial / Institutes	Religious	Schools	Total
1	Nuwara-Eliya	52,142	1,467	139	7	20	1,633
2	Hanguranketha	4,250	5,267	258	51	67	5,643
3	Walapane	28,092	9,109	356	89	100	9,654
	Total	104,484	15,843	753	147	187	16,930

Above building categorization was done after conducting the survey among buildings located in high and medium landslide hazard zones according to 1:10,000 scale landslide hazard zonation maps prepared by NBRO.

9. Results and Discussion

When exploring buildings in landslide prone areas in the Nuwara-Eliya District by sector, nearly two third of the houses (almost 64%) are located in rural regions of the district, while 17% of the houses are located in the Estate Sector. Urban housing in the district is considerably affected when compared with other Districts (nearly 17%). Among the households in Nuwara-Eliya District only 18% were female headed households which is noteworthy.

In terms of education, it is significant that, 7% of heads of households have not received any formal education. As for occupation of household members, the findings revealed that the majority of the respondents are engaged in agricultural activities (23.6%). Furthermore, there is a considerable proportion of unemployed persons in the landslide prone areas of the districts (16. 8%) which is significant to identify and further explore. It becomes apparent that 78% of settlers in Nuwara-Eliya District are members of community-based organizations.

It is important to note that in Nuwara-Eliya District (85%) of the houses had been built without obtaining the approval from any institution and among these houses 48% of the houses were constructed on steep slopes while another nearly 12% were built on the rolling slope. Further, 47% of the households use their land for agricultural purposes while 52% use their land for other purposes. In Nuwara-Eliya District, nearly 54% of the respondents stated that their households are vulnerable to floods or high winds or lightning.

Nearly 69% of the buildings located in High & Moderate hazard areas of Nuwara-Eliya District had been constructed without obtaining approval from any organization or an authority prior to construction (figure 01). The greater number of unapproved constructions had been carried out prior to 2011 and the number of unauthorized constructions has decreased since 2011.

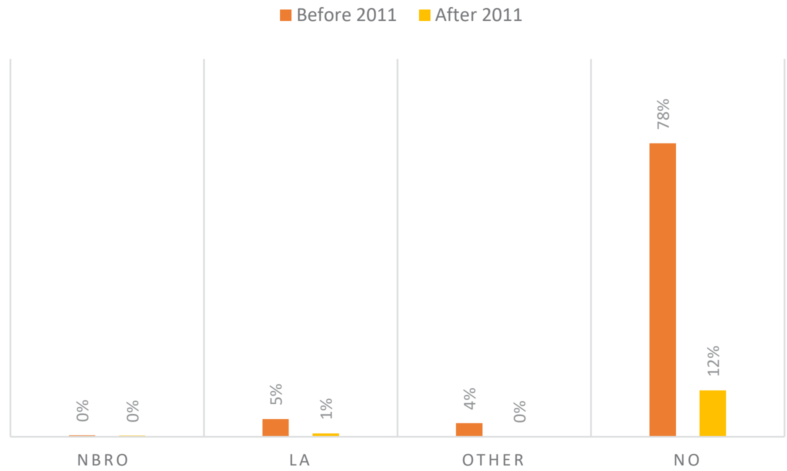


Figure 01: Approvals obtained for construction

It was observed that there is a gap in the level of awareness among the residents of the Nuwara-Eliya District with regard to the existence of disaster management committee in their respective areas. 36% of the surveyed communities did not know whether the disaster management committee exists in their villages. Such unawareness and misconception could contribute to disrupted information flow and disturb proper coordination of activities and provision of services for hazard prone individuals.

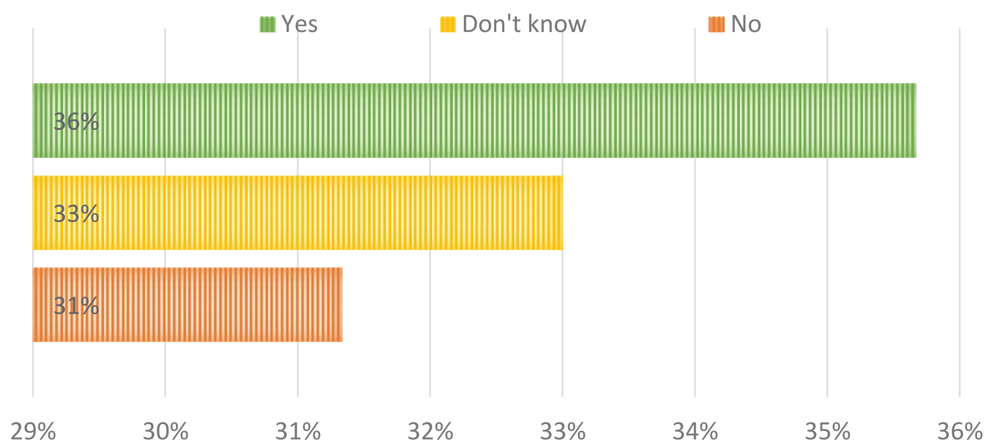


Figure 02: Availability of disaster management cycles

The study revealed that the majority of the residents in the Nuwara-Eliya District who are prone to hazards are of the opinion that they have not received any adequate disaster preparedness instruction (nearly 86%). As awareness plays a crucial role in mitigating a disaster situation this lack of instructions may create serious complications to the residents in Nuwara-Eliya District. Further, a significant number of the respondents (93.2%) stressed that they are yet to participate in disaster management activities in the last three years. Considering the number of hazard prone houses in the area it is a must to conduct disaster management activities with the active participation to allow for the communities in hazard prone area to identify and mitigate the issues and problems that they might encounter in a disaster. And the lack of such activities is major gap in empowering the hazard prone masses.

It is evident that irrespective of the occupation and expenditure levels, individuals are more in favor of being relocated in to places situated in the same GN Division (Figure 3). As the Nuwara-Eliya district is an area where there is an acute shortage of safe land, the most suitable option would be to provide multi storied housing units to the families who are intended to be relocated.

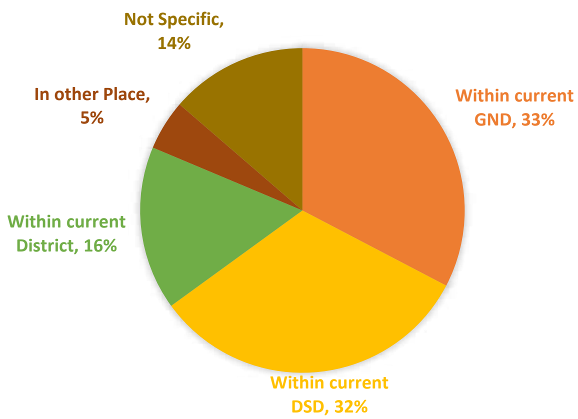


Figure 03: Preferable area to relocate vs occupation of the Head of the Household

10. Conclusion & Recommendations

The level of risk awareness among the vulnerable communities on Community Based Disaster Management Concept should be implemented all over the Nuwara -Eliya District. The conventional awareness programme models should be modified increasing the participation of the communities at risk. Participatory methods such as creating historical time lines, hazards maps, spatial maps conducting transect walks could be used to improve the participation of the communities, which would improve the awareness of the communities regarding the risk of hazards.

Change the perception on landslide disaster preparedness instructions should be given to change the existing risk perception of the residents in the District so that the communities may accurately understand the level of risk they are actually facing and take appropriate measures to reduce the risks.

Start the regular program to make aware school children of the area about disaster management. This will help to increase the level of awareness and also help to change the perception on landslide risk.

11. References

1. Jayathilake D., De Silva C. (2018) Analysis of Hazard Situation in Badulla District – Outcome of Building Survey under Landslide Risk Mapping Project. 1-9 NBRO Symposium
2. C. Ko KoP. FlentjeR. Chowdbury (2004) Landslides qualitative hazard and risk assessment method and its reliability, Bulletin of Engineering Geology and the Environment
3. Santha S. D., Sreedharan R. K., Population vulnerability and disaster risk reduction: A situation analysis among the landslide affected communities in Kerala, India. Jàmbá: Journal of Disaster Risk Studies (2010)
4. Vaculisteanu G., Niculita M., Margarint M. C., Natural hazards and their impact on rural settlements in NE Romania - A cartographical approach. Open Geosciences (2019)

A Study on House Plan Approval Process for Owner-driven Housing Construction for Resettlement Program in Kalutara District

GRY Perera[1], TRST Wijewardhana[1], TAS Sandeepani[1]

[1]Scientist, National Building Research Organisation, Sri Lanka

Abstract

Due to natural disasters and related events, damages can happen to properties and those people need to be provided with a new house that is safer and disaster-resilient. The government of Sri Lanka has initiated resettlement programs, to provide financial and technical guidance to the disaster victims, to provide them with a safer house, in a safer location. The process of providing resettlement houses after a disaster requires a large number of houses to be constructed, and therefore takes time for the procedure including site selection, selection of a contractor, and execution of the construction. Therefore, there is one option named home Owner-driven and there, by analyzing the site from a site visit, a house plan is being provided to the beneficiaries. If beneficiaries need a new plan to construct their house, they can design a plan by themselves and get approval from the NBRO before commencing the construction works of the house. In the house plan approval process, beneficiaries and officers face many issues including lesser knowledge regarding the resilient features and approval process, and also not submitting required drawings and documents. NBRO has conducted different awareness sessions to overcome these problems and also it is recommended to conduct them continuously when needed and provide an online platform for the beneficiaries to access the required information. This study will focus on the problems associated with the owner-driven house plan approval process and the solutions to improve the process to improve effectiveness and efficiency of the process with special reference to the construction of owner-driven houses in Kalutara District.

Keywords: ***Resettlement Program, House-plan Approval, Owner-driven Housing, Checklist, Resettlement Clinic***

1. Introduction

Disaster can be considered as an occurrence that damages the lives and properties and completely changes the lifestyle of people, destroying their social, economic, and cultural lives (Vijekumara, A study on the Resettlement Planning Process Applied in Post-Landslide Disaster Resettlement Projects in Sri Lanka, 2015). Sri Lanka is prone to several natural disasters such as landslides, floods, Tsunamis, coastal erosions, and cyclones. Other than that, the hazards related to environmental pollution are also likely in the Country. In the years between 2003 and 2012, about 81 million people have been affected by these hazards and the Government of Sri Lanka is coordinating with related government organizations and the general public to minimize the effects of the natural disasters in the country.

After an area is affected by a natural hazard, an important decision is needed to be taken whether to rebuild the houses in the same area or to resettle the victims in a different area (Jha, 2010). If the decision has been taken to resettle the victims in a different location, then the location needs to be easily accessible, available infrastructure facilities, disaster-free zone, and the possibility to reach community services and the process of resettlement needs to be planned and implemented properly (Vijekumara, 2015).

Several programs are being done by GoSL in collaboration with several other government institutes such as receiving the technical guidance for the resettlement program by NBRO, for disaster resilient housing construction (Vijekumara et al., 2018). In the process, NBRO has identified that damages have been happened to houses due to inadequate components in hosing constructions (Vijekumara et al., 2018). After a major natural disaster, if permanent houses are to be provided, it takes considerable time, from the land selection until the project completion because of the different constraints and a large number of houses here (Wedawatta, Ingirige, & Sugathapala, 2018), and therefore, other options are also considered.

For the design of house plans for the resettlement housing construction, there are several universal laws provided under 7 principles and it includes accommodating a wide range of individual preferences, reducing hazardous conditions and adverse consequences and appropriate function spaces and approaches, disregard of the beneficiary's mobility & posture or body size (Jha, 2010). Further, as universal problems identified by the housing construction in resettlement program it was identified that there is a limitation of using technology for fulfilling physical characteristics such as functional spaces of the house (Jha, 2010).

In the owner-driven reconstruction process, financial assistance is provided while providing the technical guidelines and regulations to build a better home (Royo-Olid, et al., 2014). The process becomes popular due to the advantages it holds. In this process, there is greater satisfaction of the beneficiary, the construction becomes quick and the results are according to the beneficiary. Also, it is not essential that the beneficiary must provide labor during construction (Royo-Olid et al., 2014).

2. Objectives

To achieve the above aim, the following objectives were formulated considering owner-driven housing construction in resettlement program;

- To identify the problems of the house plan approval process
- To identify the prevailing practices and reasons for the effectiveness
- To propose suitable solutions to address the identified problems

3. Methodology

This research is mainly qualitative type research, with data collected from NBRO, and from direct discussions with beneficiaries who are benefitted from owner-based resettlement programs. The following methodologies are adopted in identifying the existing problems in the House Plan Approval Process for Owner-driven Housing Construction.

- Existing methodologies in NBRO
    - NBRO is continuously updating the house designs to optimize the cost for the house and to acquire the required strength and other parameters such as disaster resilient structural designs. The sections of the structural elements have been reduced, without crossing the required strength limits, to reach cost effectiveness of the house at the same time it satisfies the structural and resilient requirements.
    - Any beneficiary or government officer can contact NBRO and provide comments on the designs and other problems. Seminars and awareness programs are held from time to time, to discuss the process and problems, covering the 10 Districts which are mainly prone to natural disasters.
- Discussions with the Technical officers of the DS Divisions and NDRSC officers
    - Human Settlements Planning and Training Division of NBRO has conducted several awareness sessions for the officials of District Secretariat offices who are working with NBRO for resettlement program, especially, "Home owner-driven" approach. There, the officials were informed and educated with the design changes done in the NBRO designs and also instructions were given to reduce errors in the house plans and resubmissions.
    - Further, they have collected problems faced by beneficiaries in their divisions regarding the problems they are encountering, in house plan approval process, and housing construction process. The problems were identified and clarified and possible solutions have been provided.
    - Technical officers contact NBRO officers in situations which need assistance. Then, solutions are provided, and if needed site visits are arranged too
- Resettlement clinic program was done for the beneficiaries.

As a result of the awareness program that is conducted for the technical officers, the officials of the Bulathsinghala DS office have identified that people are having social,

Figure 01: Resettlement Clinic Program

technical and financial problems regarding this program and suggested bringing a small group of people to the office and openly discuss their problems and give proper solutions. Then the resettlement clinic took place in Bulathsinhala DS office premises on 28th September 2021, with the participation of the Divisional Secretariat of Bulathsinhala, Assistant DS, NDRSC officers, NBRO officials and beneficiaries with the relevant Grama Niladari for the Region. The set of beneficiaries who have participated in the discussion were the victims of the flooding and landslide events in 2017 and entered as a beneficiary for the resettlement program. These beneficiaries have taken the installments for the foundation and have not collected their second installment.

4. Results

(i) Prescribed Measures to Address Key issues of the Preventive Resettlement Mechanism in Sri Lanka.

Table 01: Prescribed Measures to Address Key Issues

Key Issues of the Preventive Resettlement Mechanism	Measures to Address Key Issues
Poor knowledge transferring related to the technical know-how of resilient housing construction techniques to contractors, masons and the beneficiaries	Conducting awareness sessions to enhance the technical knowledge and to discuss other technical matters
Poor application of technical details for the house designs by masons and contractors	Reviewing and monitoring the construction processes
Beneficiaries think that it is an overdesign to apply disaster resilient features to a conventional type single-story house.	Conducting Knowledge sharing sessions and seminars on disaster resilient housing concepts
Inability or not adequate knowledge of private house designers in applying resilient features to the house designs of the beneficiaries	Conducting Knowledge sharing sessions and seminars on disaster resilient housing concepts
High cost to build the house with resilient features	Optimize the designs by NBRO to reach resilient construction goals while reducing the cost
High time consumption to build the house with resilient features	Skilled masons and labors and developing seedy construction methods and techniques.

(ii) Identification of problems and their causes through resettlement clinic and received plans.

Table 02: Problems and their causes in house plan approval

No	Identified Problems	Causes for the problems	Provided/ Recommended Solution
1	Delay in submitting a plan to NBRO for the approval process	No money for developing a new plan, but no plan developed by NBRO can be applied for the land	New designs should be developed for more various land types
2	The beneficiary does not like the plans developed by NBRO for the land.	Social and personal preferences	Inform them about the cost for designing a new plan and needed requirements
3	Houses designed disregard of the cost and with lesser technical guidance	Astronomy Vs Cost	Instruct the beneficiary on cost-related factors without blindly following any astronomical considerations
		Draughtsman or similar person with no technical knowledge on resilient features draw the house plan	Providing a guideline for the house designer on resilient requirements
4	When only 1 or 2 people are living in the house, especially when they are old, they do not have the intention of constructing a whole house.	650 ft2 house considered by NBRO as the basic house is not needed as only 1 or 2 people are living in the house	Identify their minimum requirement for a house and provide relevant recommendations according to that situation
5	No relevant information in the plan on the foundation details and site plan	No knowledge regarding the approval process requirements	Provide guidelines to the beneficiary at the initial stage of the process regarding the required documents and drawings
6	Column locations are not marked		
7	NBRO report is not attached with the plan		Inform them that resubmissions need to be done and it takes time if those are not properly submitted at first
8	NBRO report is attached, but the plan is not developed according to the recommendations in the report	No knowledge of this report and its importance	Strictly inform the beneficiary regarding NBRO requirements and importance of adhering to them
9	House plans with Retaining walls are submitted for approval with lesser reinforcement and lesser sections	Retaining wall: Rejection of the RW due to lack of information is not an option, but approval cannot be given for inadequate information and designs due to less r/f requirement or height such as 10 feet	Instruct people to avoid buying lands with such heavy and complex designs and constructions
			Instruct the beneficiary to consult a Chartered Engineer in such complex designs, highlighting the safety of the house and its people
10	Disobey of recommendations in approved plans: Some beneficiaries have taken the approval for a 1-story house but constructed the house for 2 or 3 stories	Not enough monitoring of the process by the relevant officers	Close monitoring of the process and gather information on the consequences of malpractices

(iii) Further, the below solutions were also provided considering all available problems.

- Prepared documents: Two documents have been prepared to give to the beneficiaries, one is to give to the beneficiaries at the initial stage when they decide to go for their plan. It describes required drawings for the approval processes and other general details for the submission of plans for approval.

  The second document is a checklist that is used when the beneficiary is submitting his/her plan for approval. Therefore, if a required document is not submitted, then the beneficiary could be informed in the first place.

Figure 02: Document 01

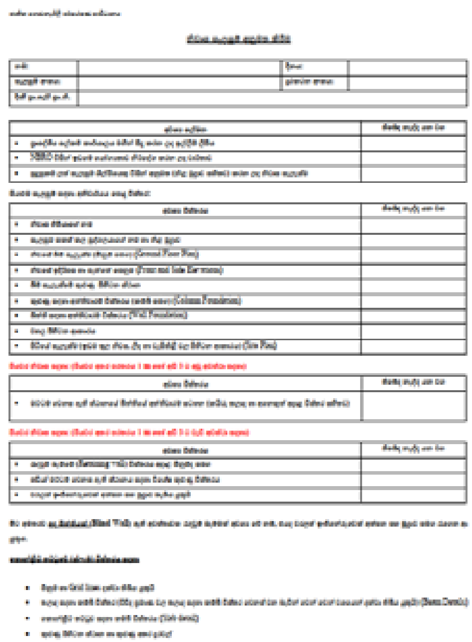


Figure 03: Document 02

- Resettlement clinic program: Up to now, one program has been conducted in the Bulathsinhala area and this could be conducted centering DS offices wherever required.
- Training programs and seminars for Technical officers, Masons and beneficiaries: Several programs have been conducted up to now, and can continue further.

(iv) Future recommendations: The following programs and activities could be recommended for the owner-driven housing construction of the resettlement program.

- Online platforms could be created to reach the required information for the house plan approval process. Then, not only the beneficiaries but also the private house plan designers and draughtsmen could get the required information online.

- The beneficiaries and victims, and people living in such possible areas need to be educated on resilient features and resilient construction. Informative sessions and discussions could be held to educate them on the practices and reasons for adopting them.
- The prepared natural hazard maps (Eg: Wind maps, landslide maps etc.) need to be more public so that before buying land, people can refer the maps by themselves on hazard zones.

5. Conclusion

For the victims of natural hazards such as landslides and flooding, the Government of Sri Lanka, with the technical guidance of NBRO and other several organizations have initiated the resettlement program, to provide disaster resilient houses, in the concept of "Build Back Better". Here, the beneficiaries have been selected and they were relocated to safer places with providing houses. The providing of houses is done through several programs and owner-driven housing construction includes houses to which are constructed by the beneficiaries and are provided with financial guidance by the GoSL.

In owner-driven housing construction, some beneficiaries would like to build their house according to their plan, without accepting the plan by NBRO. In such cases, they need to prepare a plan and submit it to NBRO for the approval process. In that process, several problems occur and they are identified through discussions and programs held.

As solutions to those issues and problems, NBRO has conducted knowledge-sharing sessions, workshops, and seminars. Further, face-to-face interviews have been done with the beneficiaries and responsible officers of DS offices to provide solutions at the same time. Also, NBRO has done alterations to its plans, to reduce the cost while including the resilient features of the house. Further, two documents have been prepared, one to distribute to the beneficiaries at the initial stage, including the documents and drawings that are needed to be submitted, and the other one is a checklist to check whether the required documents have been submitted for the approval process.

Further recommendations have been provided by this paper for increasing the effectiveness of the approval process, providing an online platform with required information in this process, and also widening the existing methodologies, to take the maximum output of the process.

6. References

1. Jha, A. K. (2010). *Safer Homes, Stronger Communities: A Handbook for Reconstructing after Natural Disasters.* Washington DC 20433: The International Bank for Reconstruction and Development / The World Bank.
2. Royo-Olid, J., Fennell, S., Davis, L., Skineer, R., Miranda, R., & Kalugalagedera, T. (2014). *Building, owning & belonging: From assisting owner-driven housing reconstruction to co-production in Sri Lanka, India, and beyond.* The European Union.
3. Vijekumara, P. A. (2015). A Study on the Resettlement Planning Process Applied in Post-Landslide Disaster Resettlement Projects in Sri Lanka. *NBRO Symposium 2015 - 'Innovations for Resilient Environment'.* Colombo: National Building Research Organization.
4. Vijekumara, P. A., Ekanayake, E. M., Anuradha, D., & Rathnajith, B. A. (2018). An assessment on Knowledge Transfer in Post Disaster Housing Construction. *Innovation for Build Back Better* (pp. 314-322). Colombo: National Building Research Organisation.
5. Wedawatta, G., Ingirige, B., & Sugathapala, K. (2018). *Long-term Sustainability and Performance of Post-disaster Housing Projects.* CIOB Bowen Jenkins Legacy Research Fund.

Determine Approach to Prioritize Landslide Mitigation Locations in Badulla District

Chanchala De Silva[1], W Nisansala Lakmali[1], WKC Kumarasiri[1]

[1]Scientist, National Building Research Organisation, Sri Lanka

Abstract

In the recent past, Sri Lanka has experienced several devastating disaster situations including landslides. Significant increase in natural and human induced landslides was observed in landslide prone areas of Sri Lanka. Parallelly the anticipated risk on communities and properties also will increase. Historically, dealing with disasters focused on disaster preparedness, emergency response, recovery and mitigation options. Most of the Disaster Risk Reduction (DRR) and Disaster Risk Management (DRM) activities claimed that they can prevent losses and alleviate the impacts of disasters. Considering that National Building Research Organisation (NBRO) has initiated programs to collect the data of communities at high-risk in the landslide prone areas of Sri Lanka. Mainly collected data have information about building units which are located on high landslide hazard areas and at the same time, about already recorded landslide incidents. Through the collected data, Community Based Disaster Risk Management (CBDRM) programs were conducted to strengthen the DRR and DRM activities within respective locality. This research is focused on prioritization of landslide prone communities to implement landslide mitigation programs within landslide prone districts. At the initial stage, Badulla District has been selected to carry out this program.

Key words: Landslide, CBDRM, Hazard, Risk, Vulnerability, Capacity

1. Introduction

Landslide is one of the major natural hazards in Sri Lanka. Under this condition there are 14 districts out of a total of 25 districts in Sri Lanka that have been declared as landslide prone districts by the National Building Research Organisation (NBRO). The NBRO has launched various projects to prevent the landslide related damages and losses. Landslide Risk Profile Development Project is the one of project that implemented from 2016 to 2021 in 10 landslide prone Districts (Badulla, Galle, Hambanthota, Kaluthara, Kandy, Kegalle, Matale, Matara, Nuwara Eliya and Rathnapura) of Sri Lanka. Main objective of this project is to develop Divisional Secretariat level landslide risk profiles in 10 landslide prone Districts and to develop a spatial database of communities at risk of landslide. There were different sub projects under this project, such as Hazard zonation mapping, Building Survey, Special Investigation Survey (SPI) and Community Based Disaster Risk Management (CBDRM) programs which conducted in particular Districts.

Integrated Landslide Hazard Zonation Mapping Program is based on an extensive field study and evaluation of six causative factor attributes and their sub factor elements. Based on the integrated landslide hazard zonation map, the building survey is carried out to collect the socio-economic data of people who are residing in landslide high hazard zones. The Building Survey has been undertaken to gather data on (i) general information (ii) demographic profile of the households (iii) land use and of characteristics of housing units (iv) construction guidelines followed to build the house (v) disaster impacts (vi) disaster preparedness (vii) disaster risk reduction measures). NBRO performs special investigations for identification of risk associated with nearby human settlements, infrastructure and plantations and provided immediate recommendations to the District and Divisional Secretaries and other Governmental institutions. Parallel to that the Landslide Special Investigation (SPI) survey has been conducted by NBRO to collect the data on families living at high risk of landslides. These high-risk locations were identified using recorded landslide, cutting failure or slope failure incidents.

To strengthen the capacity of vulnerable communities to cope with landslide disaster situations, the community-based disaster risk management mechanism has been established in each Grama Niladhari Divisions (GND). The GNDs were selected considering the number of high-risk building units located on each GND. As the first stage, GNDs with more than 100 high risk building units were selected to conduct CBDRM program. The CBDRM program consisted with several steps including establishment of CBOs, training & awareness for disaster risk reduction, community managed mitigation measures implementation and participatory evaluation and monitoring.

Under the project approaches, project team expected to develop the approach to determine appropriate community managed landslide risk reduction in landslide prone District. Main objective of this task is reducing the landslide risk in particular areas before it happens and enhance the community about their living area to identify landslide risk and inform about the solutions to reduce the landslide risk.

2. Methodology

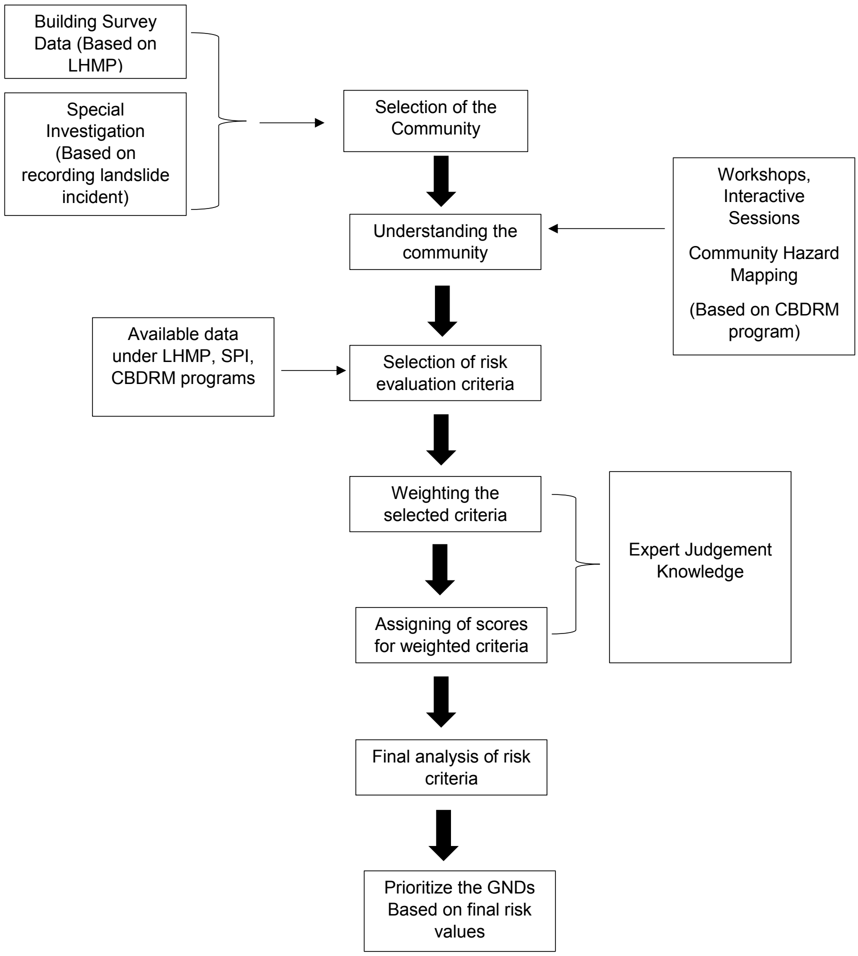


Figure 01: Methodology

3. Analysis

Badulla District has been selected to conduct this initial study to determine priority landslide mitigation locations GND wise. There were 94 CBDRM programs in GND level that has been conducted in 10 DSDs including Badulla, Ella, Haldummulla, Hali -Ela, Haputale, Kandeketiya, Passara, Soranatota, Uva Paranagama and Welimada. All 94 GNDs had more than 100 high-risk building units. The CBDRM programs were designed to conduct in an interactive way for the vulnerable community to understand well. Therefore, the community hazard mapping activity has been conducted to identify possible hazardous areas within their locality. For that community used their experience, knowledge, understanding and predictive powers to map the hazard-prone areas.

Figure 02: Community participation in CBDRM Programs

Following are the data sources used to determine the priority landslide mitigation locations in Badulla District.

(i) Building Survey on Landslide High Risk Zones

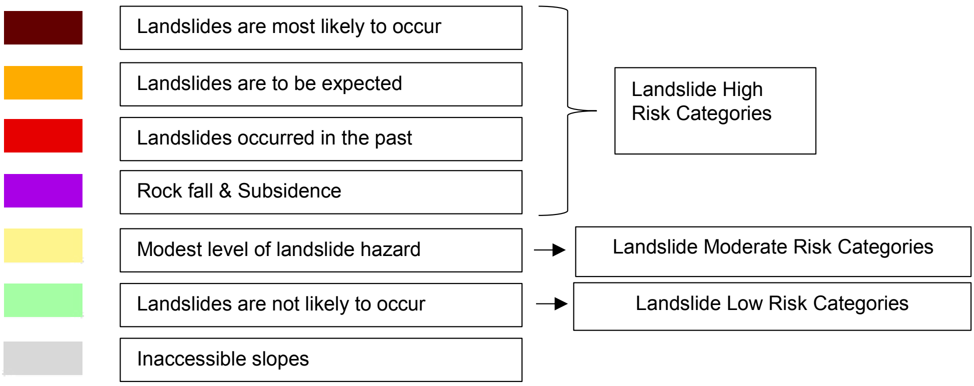


Figure 03: Landslide Hazard Zonation Map Categories

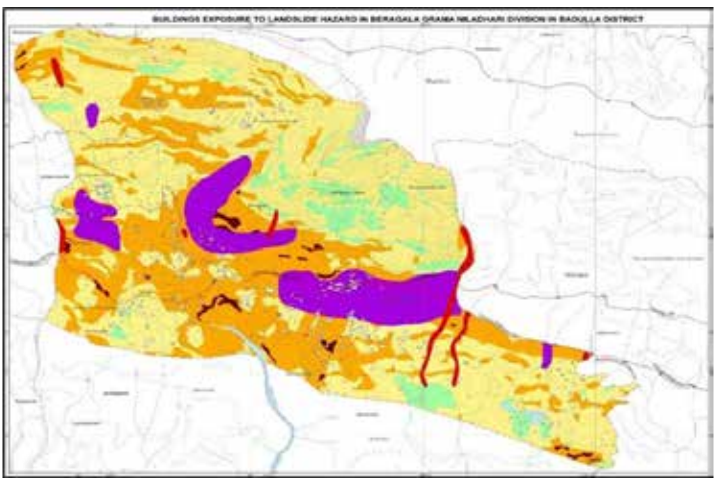


Figure 04: Landslide Exposure Map

The buildings located in the high landslide hazard zones has been selected to conducted this survey. The outputs shared in an online platform that can access the relevant officials to understand the level of exposure of the particular community in a disaster situation.

(ii) Landslide Special Investigation Survey

Figure 05: Landslide High Risk Houses

This program designed to collect the data on high-risk families identified through the observed landslide symptoms. The observation activities carried out by NBRO scientists and recommended to resettle the families due to high landslide risk.

(iii) CBDRM program - Community Hazard Mapping

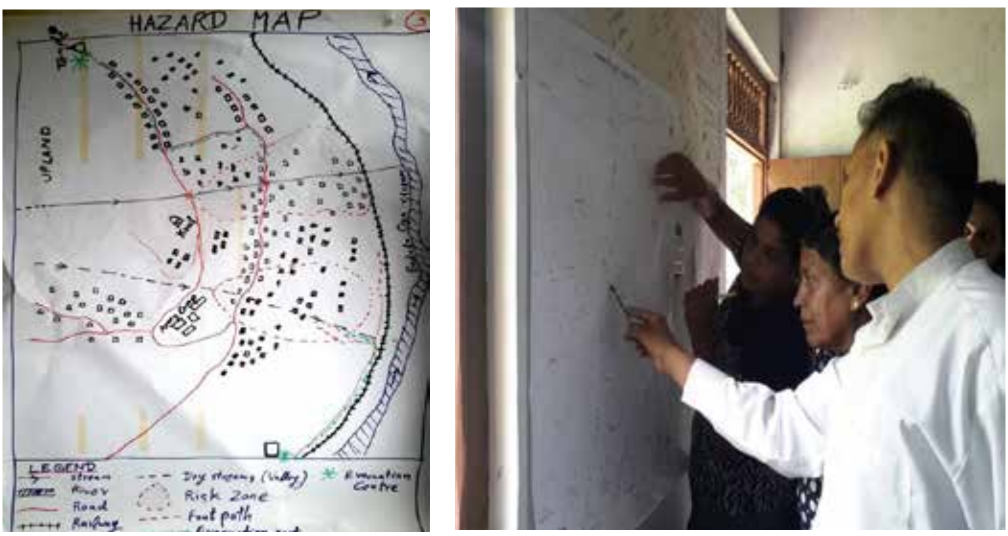


Figure 06: Community Hazard Mapping Activities

In here the landslide experts asked people to mapped the existing and possible hazard area, evacuation routes and locations, accessible roads and vulnerable community clusters of their locality. Except that the community presented their suggestions on mitigation measures that can be implemented to reduce the anticipated landslide risk.

The methodology compiled was based on standard disaster risk equation. The assessment criteria were extracted considering disaster risk equation. The criteria were defined based on Hazard, Vulnerability and Capacity. There were 3 criteria for hazard, 9 for vulnerability and 2 for capacity. All data related to the criteria were extracted from building survey, special investigation survey and CBDRM programs conducted in Badulla district.

$$Risk\ Value = Hazard * \frac{Vulnerability}{Capacity}$$

Equation 01: Disaster Risk Equation

Table 01: Criteria Selection

Hazard (H)	Vulnerability (V)	Capacity (C)
[H1] Hazard Density	***[V1]*** Number of Housing units locate within landslide high hazard zones	***[C1]*** Accommodation capacity of the nearest Evacuation Centre
	[V2] Number of Schools locate within landslide high hazard zones	
	[V3] Number of Hospitals locate within landslide high hazard zones	
[H2] Number of Landslide probable areas in the GN Division	***[V4]*** Number of Religious Places locate within landslide high hazard zones	
	[V5] Number of Commercial buildings locate within landslide high hazard zones	***[C2]*** Number of evacuation routes available
	[V6] Number of Institute buildings locate within landslide high hazard zones	
[H3] Signs of landslides observe in the vicinity of the houses	***[V7]*** Population inhabits within landslide high hazard zones	
	[V8] Number of SPI buildings locate within the GN	
	[V9] Possibility of access road to the house affect by disaster	

Criteria of [H1], [H2] and [V1] were derived from Integrated landslide hazard zonation maps available in the area. Criteria of [V2], [V3], [V4], [V5], [V6], [V7], [V9], [C1] and [C2] were derived from outputs of building survey conducted in the high hazard areas. Criteria of [V8] was derived from SPI survey conducted along with recorded landslide incidents in the area. Each criterion was arranged in to a point scale considering the histogram and its value distribution. The point scale managed to be in 2 to 6 levels as per the expert judgement on value distribution among selected GNDs. The associated scores for each level were defined in terms of their contribution to increase landslide risk. The expert judgment knowledge has been used when defining the risk level for each criterion.

The weightage values were assigned for each of the criteria considering their level of impact to landslide risk. The values were given as follows:

Table 02: Weightage values of each criteria

Criteria	***H1***	***H2***	***H3***	***V1***	***V2***	***V3***	***V4***	***V5***	***V6***	***V7***	***V8***	***V9***	***C1***	***C2***
Weight	0.6	0.25	0.15	0.25	0.15	0.15	0.05	0.05	0.05	0.15	0.1	0.05	0.6	0.4
Equal		1						1						1

After giving weight, the values were finalized by multiplying weight with assigned score values for each GNDs.

$$\text{Value} = \text{Score} * \text{Weight}$$

Equation 02: Value Equation

The final risk values were derived based on standard risk value equation. First each criterion related to hazard and vulnerability aspects combined separately. The output values multiplied with the total values of hazard and vulnerability aspects and divided by combination of capacity criteria value. The final value was taken as risk value for particular GND.

$$Risk\ Value = \frac{(H1 + H2 + H3) * (V1 + V2 + V3 + V4 + V5 + V6 + V7 + V8 + V9)}{(C1 + C2)}$$

Equation 03: Risk Value Formula

NO	Divisional Secretariat Division	GN Division	(H1) Score Hazard Density (1/5)	(H1) Weight Hazard Density (6/5)	(H1) Value Hazard Density (1/5)	(H2) Score Number of Landslide probable areas in the GN Division	(H2) Weight Number of Landslide probable areas in the GN Division	(H2) Value Number of Landslide probable areas in the GN Division	(H3) Score Signs of landslides observe in the vicinity of the houses	(H3) Weight Signs of landslides observe in the vicinity of the houses
1	Badulla	[illegible]	0.2	0.6	0.12	0.4	0.25	0.1	0.8	0.15
2		Badulla North	1	0.6	0.6	0.2	0.25	0.05	0.4	0.15
3		Badulla South	0.6	0.6	0.36	0.4	0.25	0.1	0.8	0.15
4		Badulla West	0.4	0.6	0.24	0.4	0.25	0.1	0.6	0.15
5		[illegible]	0.6	0.6	0.36	0.4	0.25	0.1	0.2	0.15
6		[illegible]	0.8	0.6	0.48	0.8	0.25	0.2	0.6	0.15
7		[illegible]	0.4	0.6	0.24	0.2	0.25	0.05	0.6	0.15
8		[illegible]	1	0.6	0.6	0.6	0.25	0.15	1	0.15
9		[illegible]	0.2	0.6	0.12	0.4	0.25	0.1	1	0.15
10		[illegible]	0.4	0.6	0.24	0.4	0.25	0.1	0.8	0.15
11		[illegible]	0.6	0.6	0.36	0.2	0.25	0.05	0.6	0.15
12		[illegible]	0.2	0.6	0.12	0.2	0.25	0.05	0.8	0.15
13		[illegible]	1	0.6	0.6	0.8	0.25	0.2	1	0.15
14		[illegible]	0.2	0.6	0.12	0.2	0.25	0.05	0.4	0.15
15	Ella	[illegible]	0.2	0.6	0.12	0.6	0.25	0.15	0.8	0.15
16		[illegible]	0.2	0.6	0.12	0.4	0.25	0.1	0	0.15
17		Halpe	0.2	0.6	0.12	0.4	0.25	0.1	0.4	0.15
18		[illegible]	0.2	0.6	0.12	0.4	0.25	0.1	0.6	0.15
19		[illegible]	0.2	0.6	0.12	0.2	0.25	0.05	0.4	0.15
20		[illegible]	0.2	0.6	0.12	0.6	0.25	0.15	0.6	0.15
21		[illegible]	0.2	0.6	0.12	0.6	0.25	0.15	0.4	0.15
22	Haldummulla	[illegible]	0.4	0.6	0.24	0.4	0.25	0.1	0.4	0.15
23		[illegible]	0.6	0.6	0.36	0.4	0.25	0.1	0.2	0.15
24		[illegible]	0.4	0.6	0.24	0.2	0.25	0.05	0.2	0.15
25		Bogoda	0.2	0.6	0.12	0.4	0.25	0.1	0.4	0.15
26		[illegible]	0.2	0.6	0.12	0.2	0.25	0.05	0.6	0.15

Figure 07: Work sheet of risk value calculation

The final risk value was normalized between 0 to 1, to have better idea on prioritization of GNDs. The minimum risk value was 0.045833333 and the maximum risk value was 1.638750000. Using following equation, the risk value was taken as normalized value.

$$\text{Risk Value Scaling} = \frac{\text{Risk Value - Risk Value (min)}}{\text{Risk Value (max) - Risk Value (min)}}$$

Equation 04: Risk Value Scaling

The final risk values were arranged in to an ascending order to get the rank of each GND. According to the ranked list, the first 20 GNDs were taken as priority mitigation locations in Badulla District.

Table 03: GND prioritization based on final risk values

Divisional Secretariat Division	GN Division	Risk Value Scale	Rank
Hali-Ela	Kokatiyamaluwa	1.0000	1
Hali-Ela	Spring Valley Estate	0.5676	2
Soranathota	Idamegama	0.5308	3
Hali-Ela	Dematawelhinna	0.5160	4
Welimada	Vidurapola	0.5115	5
Uva Paranagama	Ilukwela	0.4738	6
Kandaketiya	Hapathgamuwa	0.4609	7
Hali-Ela	Mahawaththagama	0.4512	8
Haputhale	Magiripura	0.4346	9
Uva Paranagama	Medagodagama	0.4326	10
Hali-Ela	Kadana	0.4272	11
Kandaketiya	Galauda	0.3986	12
Soranathota	Kohowila	0.3939	13
Badulla	Heennarangolla	0.3887	14
Badulla	Katupalallagama	0.3714	15
Uva Paranagama	Pitiyakumbura	0.3694	16
Badulla	Sirimalgoda	0.3470	17
Soranathota	Angoda	0.3432	18
Soranathota	Rideepana	0.3432	19
Uva Paranagama	Perawella	0.3330	20

Out of 13 DS Divisions, the analysis has identified 7 DS Divisions with 20 GNDs at the top priority on landslide mitigation programs.

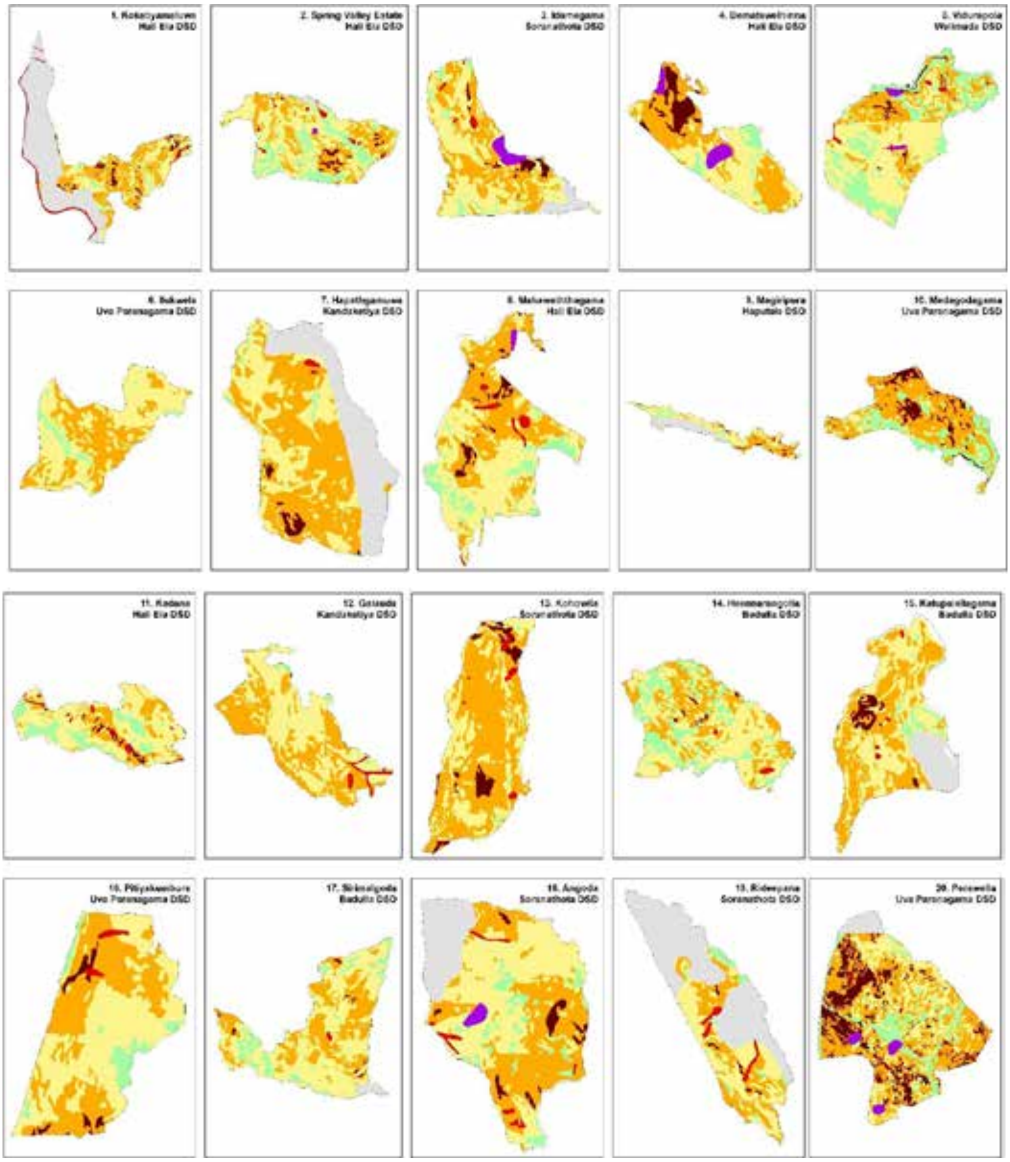


Figure 08: Prioritize GNDs with Landslide Hazard Zonation Map

4. Limitations

Finding out the data is main limitation in this study, because this study was done based on available data of building survey, SPI survey and CBDRM. Criteria scaling and weighting were done based on expert judgement. There can be data gap due to data collection time period, context of at that time & knowledge of the person who has answered the question.

5. Way Forward

Main purpose of this study is to find out the GND wise priority landslide mitigation locations in landslide prone Districts to find out the mitigation option to reduce landslide risk. For that scientific mechanism has been built by scientists considering the community aspect. The analysis is entirely dependent on expert judgmental process while concerned community is engaged in disaster risk identification. As a way forward, the two map components, Landslide Hazard Zonation Map and Community Hazard Map need to combine to have realistic idea on hazard situation in particular locality. At this stage it shows a gap that should be identified with proper mechanism.

The second thing is the verification of this output in the ground with the support from different disciplines who are involved in landslide risk mitigation activities. Finally, the outputs need to be verified with the suitable mitigation option based on the allocated budget, because all decisions need to be compatible with the economical aspect too. Under the planning aspect it is expected to use these results when decision making and final goal of this study is making the living environment safe for the community.

Effect of pH and Oxidant Concentration for Degradation of Pharmaceutical Residue β-Blocker Atenolol Molecule through Electro - Fenton Process in Wastewater

VDW Sumanasekara[1], DMMR Dissanayake[1], AM Jang[2]

[1]Scientist, National Building Research Organisation, Sri Lanka
[2]Professor, Smart Water Advanced Treatment Lab, Graduate School of Water Resources, Sungkyunkwan University (SKKU)

Abstract

The release of pharmaceuticals into natural environments, including surface water, groundwater, sediments and soil is an important environmental issue due to their potential influence on human health and ecosystems. Due to the increased interest in removal of PPCPs from water, evaluation of advanced treatment technologies, such as adsorption, membrane filtration, and advanced oxidation processes (AOPs), to address this emerging issues is highly needed. AOPs are used frequently at present. It uses the hydroxyl radical (HO•) and sulfate radical (SO_4•), which can destruct a broad range of toxic organic pollutants quickly and non-selectively. Among the AOPs, especially Fenton and Electro - Fenton processes (EF) has been extensively studied and used for the decomposition of a wide range of pharmaceuticals.

Undivided electrochemical cell was used as sacrificial iron anode and cathode to investigate the different physiochemical parameters such as pollutant concentration (C_{ATL}), electrolyte pH, and oxidant concentration. This investigation emphasized persistent pharmaceutical ingredient and - blocker atenolol degradation through electrochemically produced Fe^{2+}/ Fe^{3+} activation of oxidants peroxomonosulfate (PMS), peroxodisulfate (PDS) and hydrogen peroxide (HP) by electro-Fenton and electro-Fenton like process.

Preliminarily experimental results suggest that physiochemical parameters (C_{ATL}, electrolyte pH,) under all experimental conditions do not lead to considerable atenolol removal efficiency (15 to 25%) by electrochemical process in the absence of oxidants. However, the atenolol removal efficiency has been significantly improved up to 99% by the addition of oxidants under different physiochemical conditions.

Keywords: pharmaceutical residue, β-blocker atenolol, electro-Fenton process, wastewater

1. Introduction

The release of pharmaceuticals into natural environments, including surface water, groundwater, sediments and soil is an important environmental issue due to their potential influence on human health and ecosystems (Baena-Nogueras, et al, 2017). Nowadays, pharmaceuticals consider as Pharmaceuticals and Personal Care Product (PPCPs) which are not fully degraded after application, only partially metabolized and oxidized by processes used in wastewater treatment plants. Therefore they get into the environment in an unchanged or slightly modified form. (Babuponnusami, A.et al, 2014) PPCPs are used in large scales and are essential for improving human and animal health (Baena-Nogueras et al, 2017).

PPCPs were first detected in natural water bodies and treated wastewater in the late 1990s (Dinsdale & Guwy, 2007). The presence of PPCPs in groundwater, surface water and sediment, Wastewater Treatments Plants (WWTPs) and soils, are frequently investigated by numerous researchers (Bu et al., 2017). Therefore, the removal of PPCPs from water has generated a great interest. But, the removal efficiency of PPCPs is quite a lack in both Drinking Water Treatment Plants (DWTPs) and WWTPs due to limited infrastructures (Liu et al., 2018). As a result, the evaluation of advanced treatment technologies, such as; adsorption, membrane filtration and Advanced Oxidation Processes (AOPs), to address this emerging issues is highly needed (Bu et al., 2017).

Out of these technologies, AOPs are used frequently at present. It uses the hydroxyl radical (HO•) and sulfate radical (SO_4), which can destruct a broad range of toxic organic pollutants quickly and non-selectively (Nidheesh & Gandhimathi, 2012).

Atenolol (ATL) is one of the most frequently used beta-blockers for cardiovascular disease with its anti-vascular tonic and antiarrhythmic function (Miao et al., 2018; Ji et al, 2012). ATL has been detected in a variety of aqueous environments, such as; surface water, groundwater and hospital wastewater in the past decade (Hapeshi, E. et al, 2010). For example, ATL was quantified as high as 55 ng/L in the Vantaa River in Finland (Graaff et al., 2010), while Han River in Korea also detected ATL up to 209 ng/L (Zhang et al., 2014). Several studies have shown that ATL is unlikely to cause any acute toxicity at low concentrations as this substance is potentially resilient in the environment due to its great stability and continuous import from humans (Godoy et al, 2015). Hence, the removal of ATL from water resources is of great significance. (Hu et al., 2019).

Some AOPs have been used to degradation of ATL, and one of the successful methods in electrochemical treatment with the Boron-Doped Diamond (BDD), and Pt electrodes were applied to remove ATL by da Silva et al., 2019. This method greatly oxidize ATL but takes a long time, and the byproducts could hinder the reaction. BDD cathode is an effective material use to degradation of beta-blocker ATL as EF in AOP. It allows fast elimination of ATL (Sirés et al., 2010) but, BDD is an expensive material, and it is interesting to study more cost - effective processes.

Beta-blocker contains two kinds of reactive sites, (1) Aromatic ring (2) side chains. Atenolol degradation pathways were changed by the influence of pH and applied current densities; also, it leads to deferent inorganic and organic by product. Studies have shown that high applied current densities (20, and 30 mA/cm^{-2}) regardless of the pH can perform total N- terminal oxidation into the NO_3^{-3} except to the lower applied current densities (5 and 10 mA/cm^{-2}) (da Silva et al., 2019).

In this study, the feasibility of the electro Fenton process for the degradation of atenolol residue present in wastewater was investigated. Also, operational parameters (effect of pH and oxidant concentration) upon the removal efficiency were examined. This study provides a new approach to remove beta-blocker ATL from domestic wastewater.

2. Methodology

2.1. Materials

Atenolol ($C_{14}H_{22}N_2O_3$, MW: 266.34 gmol^{-1}), (≥98%); 2- hydroxy-3-propoxy phenylacetamide ($C_{14}H_{22}N_2O_3$) and Potassium Peroxodisulfate ($K_2S_2O_8$); PDS, were obtained from Sigma Aldrich Chemicals. Hydrogen Peroxide (H_2O_2, 30%); HP, Potassium Peroxomonosulfate; PMS, a triple salt with the composition of $2KHSO_5{\bullet}KHSO_4{\bullet}K_2SO_4$ and sodium chloride (NaCl), 99.5% were obtained from Samchun pure chemical, Korea. All chemicals used were analytical grade, and all chemical solutions were prepared using DI water (Ultima Duo, 200). And Sodium hydroxide and sulphuric acid aqueous solutions were used to adjust the pH. The continuous current density was supplied by DC power supply (model LPS-3031P NDE), and the electrolyte was magnetically stirred by magnetic stirrer (model IKA C MAC MS4). Two mild iron (Fe) electrode were used anode and cathode. Calibrated glassware and pipette were used to perform the laboratory experiment. The solution pH measurements were performed using a HACH-HQ40d, USA digital pH meter, the concentration of samples was measured using corresponding absorption value by HACH-DR 6000 UV-VIS spectrophotometry.

2.2. Experimental Setup

Experiments were conducted at room temperature in an open, undivided electrochemical cell reactor which consists of mild Fe anode and Fe cathode with the active surface area of 12.5 cm^2 (10 cm X 2.5 cm X 0.5 cm). The power connected in parallel through a DC regulated power supply (LPS- 3031P; NDE) at an inter-electrode distance of 2 cm in the electrolytic cell. A 500 mL capacity glass beaker containing 250 mL electrolyte solution was used to as batch reactor.

The experiment was running with known atenolol concentration and with the controlled experimental conditions as initial pH and under-known oxidant concentrations (0.1 mM) of PMS, PDS and HP. 1000 ppm NaCl solution was used as an ion exchanging through the electrolyte solution. Figure 01 shows the schematic diagram of the experimental batch reactor with electrocoagulation cell.

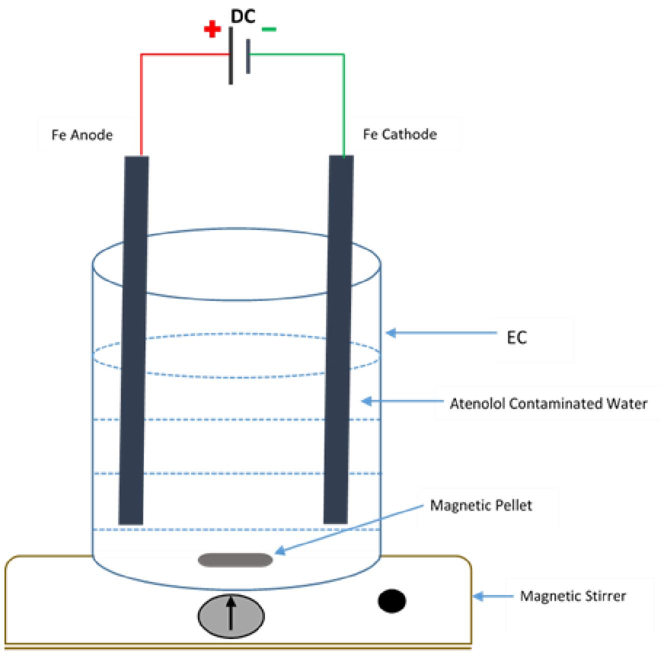


Figure 01: Schematic representation of electrocoagulation cell

2.3. Analytical methodology

Prior to the start of electrolysis, the electrolyte solution was stirred magnetically at a constant rate of 200 rpm. The atenolol concentration in the bulk solution was used as the initial concentration (C_0). Experiments were performed under constant applied current density, the initial pH and oxidant concentration of the solution is maintaining at 7 for 60 minutes. During the electrolysis, 3 mL liquid samples (aliquots) were withdrawn at regular time intervals and then filtered through a PVDF membrane filter with 0.45 µm sized pores. The initial concentration (C_0) and concentration at time't' (C_t) of the atenolol were estimated under maximum absorption wavelength (max - 224 nm) using UV – visible spectroscopy (KACH DR 6000). Since there was no change in peak positions as well as no new peaks were observed in the absorption spectrum of Atenolol during the degradation. The absorbance is proportional to the concentration of the Atenolol. The atenolol removal efficiency was calculated by the following equation 3.1 (Govindan et al., 2014; Nsubuga et al., 2019).

$$\text{Removal efficiency } (\%) = ((C_0\text{-}C_t)/C_0) \text{ x } 100 \qquad 3.1$$

Where, C_0 - initial concentration and C_t - concentration of atenolol at time't'

3. Results and Discussion

Three experiments were carried out to evaluate the effect of ATL removal efficiency in different physiochemical parameters such as ATL concentration, initial solution pH and oxidant concentration. All the experiments were carried out with same electrolysis time within 60 minutes.

3.1. Effect of ATL concentration

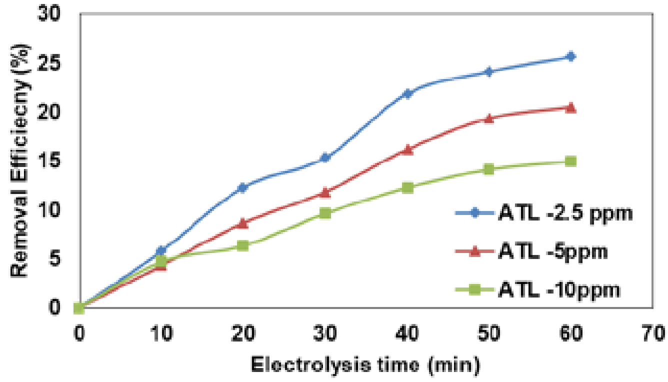
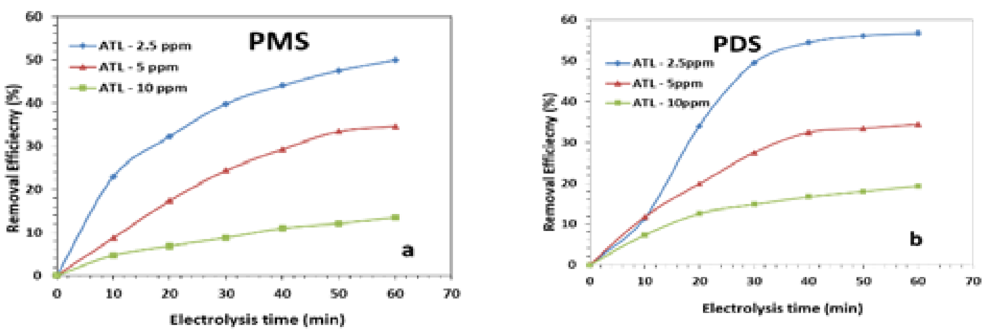


Figure 02: ATL Removal efficiency in absence of oxidant (Control experiment)

Control experiments were carried out for the two different physiochemical parameters; ATL concentration (C_{ATL}), initial solution pH. No considerable removal efficiency was found in the absence of oxidant in those physiochemical parameters, indicating that the oxidant play a major role to ATL degradation. 25.6% of maximum removal efficiency showed during lower CATL that is 2.5 ppm. With respect to that, ATL removal efficiency using mild Fe electrode was very slow and degradation was poor without oxidant and it only removed 25 % ATL within 60 minute electrolysis time.

3.1.1. Effect of C_{ATL} in the presence of oxidant



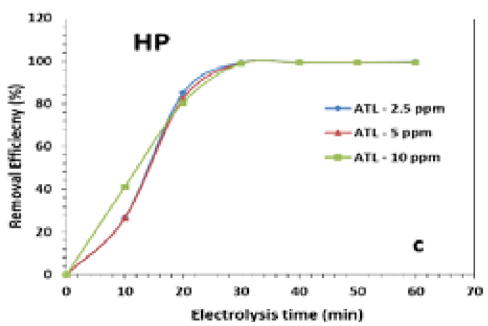


Figure 03: ATL Removal efficiency with CATL (a) in presence of PMS;(b) in presence of PDS; (c) in presence of HP, experiment condition: initial pH – 7, CNaCl - 1000 ppm, applied current - 200 mA and CPMS - 0.1 mM

Figure 03(a), 03(b) and 03(c) show the experiment results of influence of ATL concentration with respect to degradation for the same conditions of ATL with regards to different oxidants of PMS, PDS and HP. Different ATL concentrations with PMS were observed (Figure 03(a)) in following conditions. Sixty minute removal efficiency was decreased while increasing ATL concentration. Maximum removal efficiency; 50.0% was seen in 2.5 ppm ATL and at 5 ppm and 10 ppm ATL concentrations it was 34.6% and 13.5%, respectively. ATL removal efficiency with PDS was also similar to trend observed with PMS (Figure 3.2(b)), with increased ATL concentration the removal efficiency decreased. The removal efficiency for 2.5 pm, 5 ppm and 10 ppm of ATL were 56.8%, 34.5% and 19.2%, respectively. They reached the maximum removal efficiency within 50 minute of electrolysis.

Figure 03(a) and 03(b) also indicate considerable acceleration of ATL removal in 2.5 ppm for PMS and PDS than other concentrations (5 ppm and 10 ppm). These reached around 50% of ATL removal within 60 min using 0.1mM PMS and PDS in 2.5 ppm of ATL, respectively. Figure 03(c) shows <99.0% of ATL removal was reached in all the ATL concentrations within 30 minutes of electrolysis. Since, HP was used as the effective oxidant than PMS and PDS that, contribute to degrade all strengths of ATL under the same experiment conditions. Indeed a high oxidation power of HP has much greater ability to proceed to remove all radicals compared to PMS and PDS under same experimental conditions.

3.2 Effect of pH at C_{ATL} 2.5 ppm

3.2.1 Effect of pH at ATL 2.5 ppm without oxidant

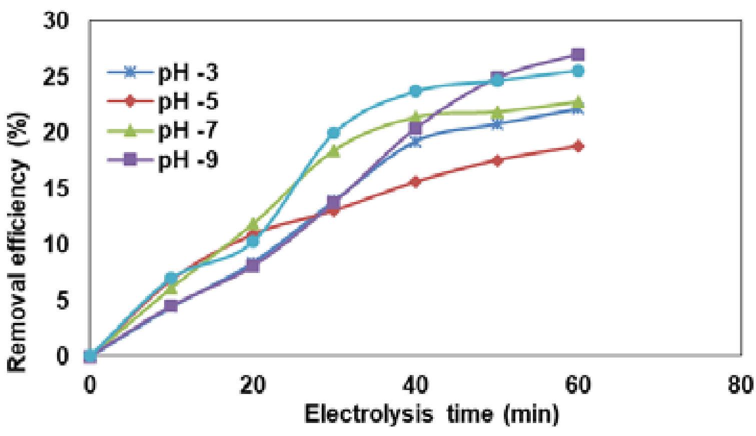


Figure 04: ATL removal efficiency with pH in absence of oxidant, experimental condition: C_{ATL} - 2.5 ppm, C_{NaCl} -1000ppm, applied current 200 mA and C_{HP} - 0.1mM

The removal efficiency at different pH levels varied from 18% to 28% in absence of oxidant (figure 04) in following order. 18.8%; pH 5 < 22.1%; pH 3 < 22.7%; pH 7 < 25.5%; pH 11< 27.0%; pH 9. Accordingly, the ATL removal efficiency in absence of oxidant with different pH do not show a considerable increment. It reached maximum of 28% in pH 9 within 60 minute of electrolysis.

3.2.2. Effect of pH presence of Oxidants

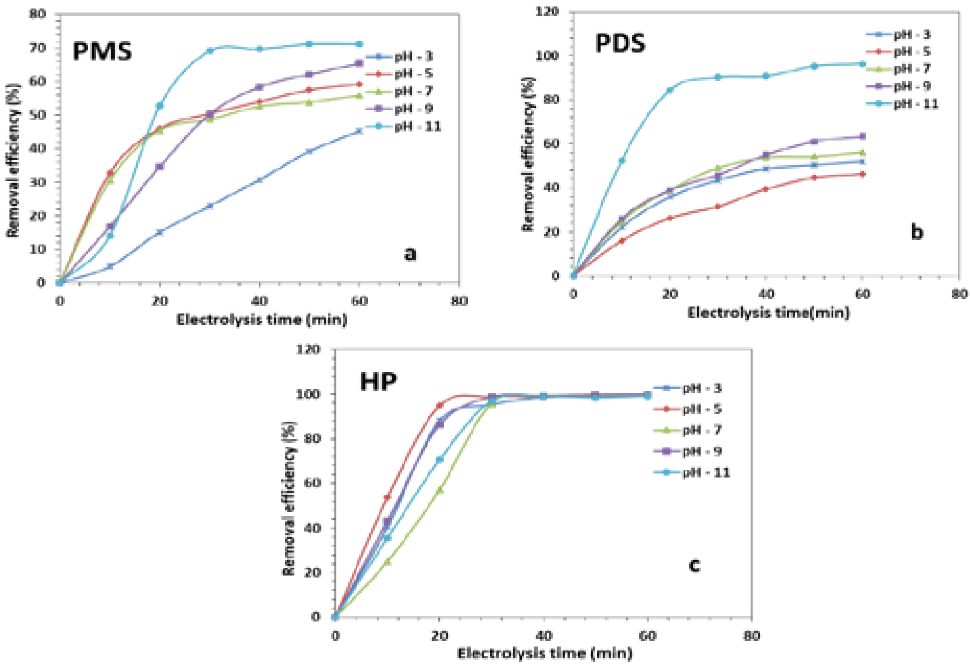


Figure 05: ATL removal efficiency with pH, (a) in presence of PMS, , (b) in presence of PDS, , (c) in presence of HP, experimental condition: C_{ATL} 2.5 ppm, C_{NaCl} -1000ppm, applied current 200 mA, C_{PMS} 0.1mM

The ATL removal efficiency increased in following order while PMS was used as the oxidant: pH - 11; 71.14% > pH - 9; 65.4% > pH - 5; 59.3% > pH - 7; 55.8% > pH - 3; 45.2%. Figure 05(a) indicates that the basic medium is more favorable to remove ATL than acidic medium with PMS. Maximum removal efficiency was reached within 30 minutes of electrolysis at all pH levels except for pH - 3. This graph shows the removal efficiency was highest at pH - 11 and removal efficiency observed an increasing trend with the pH. Therefore, the basic medium shows a greater removal efficiency than acidic conditions with PMS.

The ATL removal efficiency at different pH levels with PDS varied from 40% to 95% as, pH - 5; 46.2% < pH - 3; 52.0% < pH - 7; 56.2% < pH - 9; 63.4% < pH - 11; 96.4%. Figure 05(b) shows that a considerable increment of ATL removal in basic medium ie in pH - 11. The removal efficiency increases from 60% to 95%, while pH increases from pH - 3 to pH - 11.

The variation of ATL removal efficiency of pH with HP is contrast when compare the results of PMS and PDS as shown in Figure 05(c). With the same experiment conditions, it was seen more than 99% of ATL removal efficiency with HP within 30 minutes of electrolysis at all pH levels. Hence, there was no considerable influence from pH level contrast to the PMS and PDS where removal efficiency increased with the pH.

3.3. Effect of oxidant concentration

Four different oxidant concentrations; 0.05 mM, 0.10 mM, 0.15 mM and 0.2 mM, were used in this experiment while keeping other experimental conditions same.

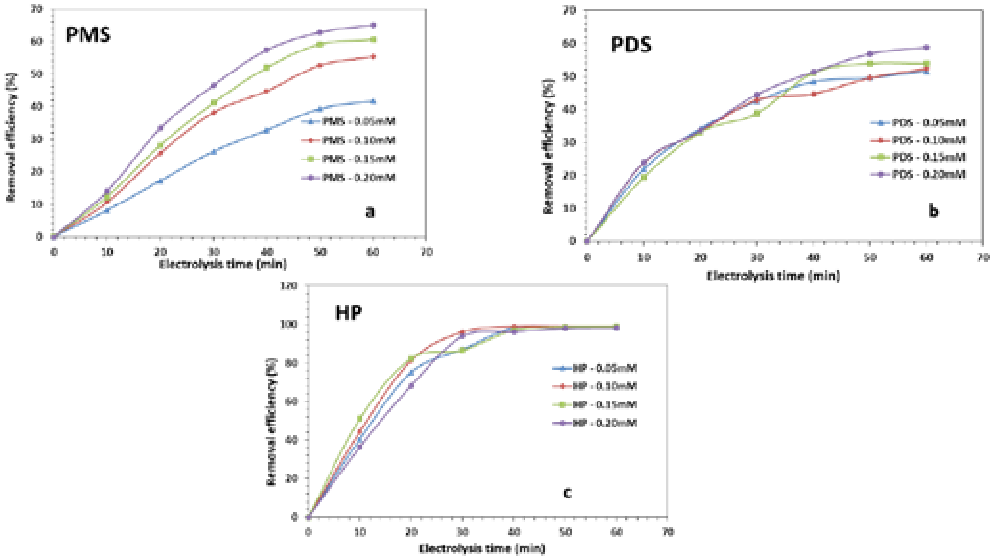


Figure 06: ATL removal efficiency (a) with PMS concentration, (b) with PDS concentration, (c) with HP Concentration, experimental condition: C_{ATL} -2.5 ppm, C_{NaCl} -1000ppm, applied current - 200 mA, pH - 7

Figure 06(a) shows the ATL removal efficiency with varied PMS oxidant concentrations. According to the figure, ATL removal efficiency increased with increasing oxidant concentration as per the following order: 0.05 mM; 41.8 %< 0.10 mM; 55.3 %< 0.15 mM; 60.6% <0.20 mM; 65.1%.

Figure 06(b) shows the ATL removal efficiency with varied PDS concentrations. Accordingly, no considerable increment was seen with different oxidant concentrations. All the oxidant concentrations yield approximately 50% removal efficiency. The variation of removal efficiencies are as follows; 0.05 mM; 51.6 %< 0.10mM; 52.4 %< 0.15 mM; 53.9 % <0.20 mM; 58.9%. Figure 06(c) shows the ATL removal efficiency with varied HP concentrations. The ATL removal efficiency reached more than 99% with all HP concentrations.

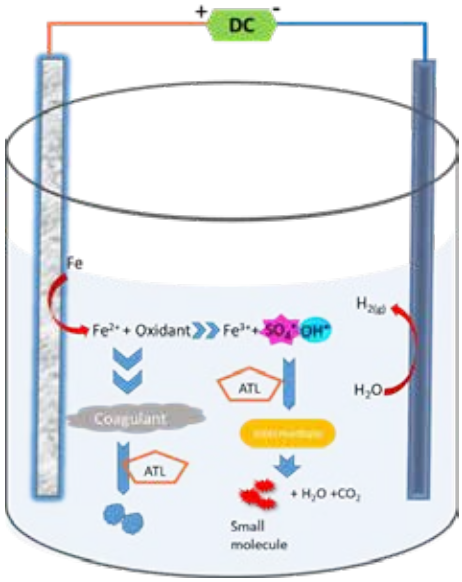


Figure 07: Schematic representation for electro Fenton and Fenton like degradation of ATL molecule in the presence of oxidant

Figure 07 presents the schematic representation of electro Fenton and Fenton like degradation of ATL molecule in the presence of oxidant. The two iron electrodes were used as an anode and cathode reactions occurred in the separate electrode. In the absence of oxidant, the reaction 1 and 2 were occurred as anodic reactions and reaction 3 occurred as cathode reaction. These set of reactions take place only when electrocoagulation process occurred in the electrochemical oxidation. This may be the reason for not observing ATL removal efficiencies with pH as physicochemical parameter.

3.4 Chemical reactions occur inside the electro-chemical cell

In normal condition where oxidants are absent, following anodic and cathodic reactions shown in (1) , (2) and (3) occur inside the electro-chemical cell which is known as the electro Fenton and Fenton like degradation of ATL molecule(Govindan et al.,2014).

Anodic reaction

$$4Fe_{(s)} \rightarrow 4Fe^{2+}_{(aq)} + 8e^{-} \qquad (1)$$

$$4Fe^{2+}_{(aq)} + 10H_2O_{(l)} + O_{2(aq)} \rightarrow 4Fe(OH)_{3(s)} + 8H^{+}_{(aq)} \qquad (2)$$

Cathodic reaction

$$8H^{+}_{(aq)} + 8e^{-} \rightarrow 4H_{2(g)} \qquad (3)$$

However, the anodic and cathode reactions change with the different oxidants. When the PMS used as an oxidant, the equation (4) to (7) occurred at the anode and cathode.

Anodic reaction

$Fe^{2+} + HSO_5^- \rightarrow Fe^{3+} + SO_4^{\bullet-} + OH^-$ (4)

$Fe^{3+} + HSO_5^- \rightarrow Fe^{2+} + SO_5^{\bullet-} + H^+$ (5)

$HSO_5^- + SO_4^{\bullet-} \rightarrow SO_5^{\bullet-} + SO_4^{2-} + H^+$ (6)

$SO_4^{\bullet-}$ + Organics $\rightarrow$ intermediates $+CO_2 + H_2O$ (7)

When the PDS used as an oxidant, the equation (8) to (10) occurred at the anode.

$S_2O_8^{2-} + 2Fe^{2+} \rightarrow 2Fe^{3+} + 2SO_4^{\bullet-}$ (8)

$Fe^{2+} + SO_4^{\bullet-} \rightarrow Fe^{3+} + SO_4^{2-}$ (9)

$SO_4^{\bullet-}$ +Organics$\rightarrow$intermediates $+CO_2 + H_2O$ (10)

When the HP used as an oxidant, the equation (11) to (13) occurred at the anode.

$Fe^{2+} + H_2O_2 \rightarrow Fe^{3+} + HO^{\bullet-} + OH^-$ (11)

$Fe^{3+} + H_2O_2 \rightarrow Fe^{2+} + HO^{\bullet}_2 + H^+$ (12)

$HO^{\bullet}$ +Organics$\rightarrow$intermediates $+CO_2 + H_2O$ (13)

The reaction (4) to (10) occurred in iron anode with sulfate radical for that reaction called Fenton like reaction and the reaction (11) to (13) occurred at iron anode with hydrogen peroxide called Fenton reaction and these two - process called as Fenton like oxidation process and Fenton oxidation process.

These reactions clearly indicate how organic pollutant degradation evolves with sulfate radical and hydroxyl radicals. The final products of degradation were CO_2, H_2O and intermediate molecules, which has to be identified.

According to the previous research shows that PMS and PDS were effective oxidants for treating wastewater contaminated with pharmaceuticals than HP oxidant (Govindan et al., 2014).However, in this study HP shows more than 99% ATL removal efficiency with pH.

4. Conclusion

According to the results, electrochemical degradation of Atenolol using PDS, PMS and HP is a feasible method to eliminate beta blocker atenolol. Among them HP was the most feasible oxidant which showed more than 98% removal efficiency during the considered pH range of pH 3 to pH11.. It means $OH^{\bullet}$ showed high reactivity towards ATL compared to $SO_4^{\bullet-}$. $OH^{\bullet}$, which played an important role in the electrochemical oxidation process with the physiochemical parameters. Further, PMS and PDS showed the most efficient removal under low concentration of pollutant while, HP observed 100% removal efficiency for any pollutant concentrations. Therefore, this study concludes that HP is a better oxidant than PMS and PDS to treat the β- Blocker groups (ATL) pharmaceutical wastewater.

5. References

1. Babuponnusami, A., & Muthukumar, K. (2014). Journal of Environmental Chemical Engineering A review on Fenton and improvements to the Fenton process for wastewater treatment. Journal of Environmental Chemical Engineering, 2(1), 557–572. https://doi.org/10.1016/j.jece.2013.10.011
2. Baena-Nogueras, R. M., González-Mazo, E., & Lara-Martín, P. A. (2017). Degradation kinetics of pharmaceuticals and personal care products in surface waters: photolysis vs biodegradation. Science of the Total Environment, 590–591, 643–654. https://doi.org/10.1016/j.scitotenv.2017.03.015
3. Bu, L., Zhou, S., Shi, Z., Bi, C., Zhu, S., & Gao, N. (2017). Iron electrode as efficient persulfate activator for oxcarbazepine degradation: Performance, mechanism, and kinetic modeling. Separation and Purification Technology, 178, 66–74. https://doi.org/10.1016/j.seppur.2017.01.007
4. da Silva, S. W., do Prado, J. M., Heberle, A. N. A., Schneider, D. E., Rodrigues, M. A. S., & Bernardes, A. M. (2019). Electrochemical advanced oxidation of Atenolol at Nb/BDD thin film anode. Journal of Electroanalytical Chemistry, 844(January), 27–33. https://doi.org/10.1016/j.jelechem.2019.05.011
5. Dinsdale, R. M., & Guwy, A. J. (2007). Multi-residue method for the determination of basic / neutral pharmaceuticals and illicit drugs in surface water by solid-phase extraction and ultra performance liquid chromatography – positive electrospray ionisation tandem mass spectrometry. 1161, 132–145. https://doi.org/10.1016/j.chroma.2007.05.074
6. Godoy, A. A., Kummrow, F., & Pamplin, P. A. Z. (2015). Occurrence, ecotoxicological effects and risk assessment of antihypertensive pharmaceutical residues in the aquatic environment - A review. Chemosphere, 138, 281–291. https://doi.org/10.1016/j.chemosphere.2015.06.024
7. Graaff, M. S. De, Vieno, N. M., Kujawa-roeleveld, K., Zeeman, G., & Temmink, H. (2010). Fate of hormones and pharmaceuticals during combined anaerobic treatment and nitrogen removal by partial nitritation-anammox in vacuum collected black water. Water Research, 45(1), 375–383. https://doi.org/10.1016/j.watres.2010.08.023
8. Govindan, K., Raja, M.,Noel,M., James, E.J. (2014) Degradation of pentachrorophenol by hydroxyl radical and sulfate radicals using electrochemical activation of peroxomonosulfate, peroxodisulfate and hydrogen peroxide. Jurnal Hazard. Mater, 272,42-51
9. Hapeshi, E., Achilleos, A., Vasquez, M. I., Michael, C., Xekoukoulotakis, N. P., Mantzavinos, D., & Kassinos, D. (2010). Drugs degrading photocatalytically: Kinetics and mechanisms of ofloxacin and atenolol removal on titania suspensions. Water Research, 44(6), 1737–1746. https://doi.org/10.1016/j.watres.2009.11.044

10. Hu, J., Jing, X., Zhai, L., Guo, J., Lu, K., & Mao, L. (2019). BiOCl facilitated photocatalytic degradation of atenolol from water: Reaction kinetics, pathways and products. Chemosphere, 220, 77–85. https://doi.org/10.1016/j.chemosphere.2018.12.085
11. Liu, Xiaocheng, Zhou, Y., Zhang, J., Luo, L., Yang, Y., Huang, H., … Mu, Y. (2018). Insight into electro-Fenton and photo-Fenton for the degradation of antibiotics: Mechanism study and research gaps. Chemical Engineering Journal, 347(April), 379–397. https://doi.org/10.1016/j.cej.2018.04.142
12. Miao, D., Peng, J., Zhou, X., Qian, L., Wang, M., Zhai, L., & Gao, S. (2018). Oxidative degradation of atenolol by heat-activated persulfate: Kinetics, degradation pathways and distribution of transformation intermediates. Chemosphere, 207, 174–182. https://doi.org/10.1016/j.chemosphere.2018.05.068
13. Nidheesh, P. V., & Gandhimathi, R. (2012). Trends in electro-Fenton process for water and wastewater treatment: An overview. Desalination, 299, 1–15. https://doi.org/10.1016/j.desal.2012.05.011
14. Sirés, I., Oturan, N., & Oturan, M. A. (2010). Electrochemical degradation of -blockers. Studies on single and multicomponent synthetic aqueous solutions. Water Research, 44(10), 3109–3120. https://doi.org/10.1016/j.watres.2010.03.005 Sirés, I., Oturan, N., & Oturan, M. A. (2010). Electrochemical degradation of -blockers. Studies on single and multicomponent synthetic aqueous solutions. Water Research, 44(10), 3109–3120. https://doi.org/10.1016/j.watres.2010.03.005
15. Zeng, C., Ji, Y., Zhou, L., Zhang, Y., & Yang, X. (2012). The role of dissolved organic matters in the aquatic photodegradation of atenolol. Journal of Hazardous Materials, 239–240, 340–347. https://doi.org/10.1016/j.jhazmat.2012.09.005
16. Zhang, T., Chen, Y., Wang, Y., Le Roux, J., Yang, Y., & Croué, J. P. (2014). Efficient peroxydisulfate activation process not relying on sulfate radical generation for water pollutant degradation. Environmental Science and Technology, 48(10), 5868–5875. https://doi.org/10.1021/es501218f

Assessment of Non-Occupational Exposure Risk to Air-Borne Asbestos Fibre-Occupants Living in Different Urban Environmental Conditions in the Colombo District, Sri Lanka

HD Kumarapeli[1], HDS Premasiri[2], DMMR Dissanayake[1], NKPMM Perera[1]

[1]Scientist, National Building Research Organisation, Sri Lanka
[2]Director, National Building Research Organisation, Sri Lanka

Abstract

The sound absorption capacity, high tensile strength, resistance to fire, heat, electrical, chemical and affordability of asbestos have resulted asbestos in a wide range of commercial applications. However, recently it has been identified that asbestos cause serious health impacts to human. The health risks and impacts associated with the exposure to asbestos depend on the asbestos fibre type, concentration and duration of exposure. Hence, the use of most asbestos fibre types was banned, and the Chrysotile asbestos which have minimum risk in the group is the only type used in most of commercial applications today. In Sri Lanka, Chrysotile asbestos fibres are used predominantly in the fiber-cement roofing and ceiling sheets manufacturing industry.

Although several Countries have studied and assessed the outdoor and indoor exposure levels of asbestos fibres, studies in the similar capacity are limited in Sri Lanka. Therefore, this study aimed at assessing the exposure levels of asbestos fibre in the household environment. The study was done in the houses of Colombo District, Sri Lanka. Sampling locations were selected to represent urban (Colombo City limits), sub-urban (about 15 km away from City limits) and peri-urban (about 30 - 40 km away from City limits) areas in Colombo District having varying housing densities. Samples were collected from different household types with and without asbestos roofing. The methodology stipulated by National Institute of Occupational Safety & Health (NIOSH 7400) for the sampling and analysis of asbestos fibre by using Phase Contrast Microscope (PCM) were used in the study.

The counted asbestos fibre levels in the two utility areas (bed room, living room) in houses, are in the range of 0 to 0.00102 fibre/ cc depending on the environment conditions and house type. The fibre exposure level in urban households were comparatively high compared to the peri-urban households. This may be due to the high housing density or contribution from other activities in urban areas compared to peri-urban areas. The average fibre concentration levels recorded at all selected households in all three urban environmental conditions were below the US Environmental Protection Agency (US-EPA) permissible levels of 0.0009 fibers/ cc for asbestos fibres in non-occupational buildings; residential houses. The comparison of fibre exposure levels of houses with Chrysotile roofing sheets were higher by about 36 - 41% compared to houses without Chrysotile roofing sheets in same urban environmental condition.

Key words: chrysotile fibre, indoor environment, permissible level

1. Introduction

Asbestos is a naturally occurring mineral fiber. The six minerals commonly referred to as asbestos come from two distinct groups of minerals. One known as serpentines (chrysotile, white asbestos); while the other group is the amphiboles (amosite, brown asbestos; crocidolite, blue asbestos; anthophyllite; tremolite and actinolite). While both are all silicate minerals, the two groups are chemically and mineralogically distinct and all have their distinctive asbestiform crystal habit in common.

Asbestos was widely used in products due to its heat resistant characteristics and durability. Asbestos containing insulation, gaskets, and packing have been used in conjunction with high temperature equipment such as boilers, turbines, steam pipes, pumps, valves, and furnaces. Asbestos containing materials were also commonly used during the construction of homes and offices, as well as on ships and in industrial settings.

Asbestos products became popular in Sri Lanka as substitute for building material because of scarcity of other building materials such as timber, clay tiles. According to the statistics, for more than 60 years Sri Lanka has been importing chrysotile asbestos (white Asbestos) from various Countries. Though there are many forms of Asbestos, Sri Lanka imports only the white variety of Asbestos (Chrysotile) for production of roofing and ceiling sheets, where Asbestos fibres are mixed with cement (cement act as a binding agent reducing fiber escape).

The harmful exposure to Asbestos fiber occurs by inhaling air containing fiber. When the fiber becomes airborne, it can easily be transfer to the human body through the respiratory system. Depending on their size and dimension, inhaled fibres can penetrate the respiratory tract to the distal airways and into the alveolar spaces.

It has already been scientifically proven that blue and brown Asbestos fiber can cause cancer, however, health impacts studies related to white Asbestos are on debate due to many reasons. Numerous studies have established the health impacts of long - term exposure to Asbestos fibers in industrial environment. However, even globally the studies on exposure of occupants to Asbestos fibers in household environment are very much limited. Since high levels of asbestos fiber in air can cause adverse health effects people in non-occupational environment, it is important to know the concentration of fiber in their breathing air.

In Sri Lanka, Chrysotile cement fiber roofing sheets and ceiling sheets are widely used for housing. Common to any fibre product the occupants of the buildings are potentially exposed to airborne asbestos fiber that could result from natural decay & degradation of cement fiber material, release of fiber from exposed surfaces, from routine housekeeping, maintenance and in renovation works. The occupants can be exposed to fiber contaminated air from both outdoor sources as well as from indoor sources as the quality of indoor air depends both on the outdoor air quality and on the strength of emissions of indoor sources. In most occupied spaces, there is a continuous exchange of air with the outside. Therefore, fiber contaminated outdoor air are likely to be present in indoors.

Indoor air quality has only recently become the focus of intensive research studies particularly because people spend as much as 80 - 90% of our time in enclosed spaces.

Assessing the risk of non-occupational exposure to air borne Asbestos fibers.

Many Countries engage in mining Asbestos fibers and fiber processing have established safe occupational exposure limits for Asbestos fibres in breathing air. Few other Countries have also established the non-occupational exposure levels for air borne asbestos fiber as depicted in the table below (Table 1), where the permissible fiber count in the breathing air is much low. Comparing the presence of fiber in non - occupational breathing air with non-occupational safe permissible levels established we can assess the level risk from exposure to fibres. Based on the risk level necessary control measures can be proposed to mitigate the risks; covering the emission sources, or removing degraded sections and diluting air fiber concentrations by good ventilation and etc.

Table 01: The maximum permissible levels of exposure to respirable asbestos fibers recommended by international agencies and Countries in their standard

Reference sources	Recommended values (fibers/cc)
OSHA (Occupational Safety and Health Administration - USA)	0.1
NIOSH (National Institute for Occupational Safety and Health - USA)	0.1
MSHA (The Mine Safety and Health Administration of the United States Department of Labor)	2
ACGIH (The American Conference of Governmental Industrial Hygienists)	2
Indian Industrial Standard	0.5
US – EPA (non-occupational)	0.0009
Russia (Ambient Air quality)	0.06
WHO (proposed by authors in a population of whom 30% are smokers, the excess risk due to lung cancer would be in the order of 10-6 - 10-5).	0.0005 (life time exposure)

2. Objectives

The paper presents the non-occupational exposure risk to air borne Asbestos fibers of occupants living in three different urban environmental conditions in the Colombo District; densely populated urban areas, sub-urban and peri- urban areas with moderate and low housing densities. The study examined the;

i. Compliance of indoor airborne fiber levels with the maximum permissible levels of exposure to respirable asbestos fibers recommended by international agencies and Countries

ii. Variation of indoor air borne fiber concentration in houses located in three different urban environmental conditions

iii. Variation of indoor air borne fiber concentration in houses with and without Asbestos in roofing and ceiling.

3. Methodology

3.1. Selection of sampling sites and sampling locations

The sampling sites were selected by considering the urban, sub-urban and peri-urban environmental conditions in Colombo District. Special consideration was given when selecting households based on utilization of the asbestos as per the following criteria.

- Houses with Asbestos roof only (ARO)
- Houses with non-Asbestos roof only (NARO)
- Houses with Asbestos roof and Asbestos Ceiling (AR&AC)
- Houses with Asbestos roof and non-Asbestos Ceiling (AR&NAC)
- Houses with non-Asbestos roof and Asbestos Ceiling (NAR&AC)
- Houses with non-Asbestos roof and non-Asbestos Ceiling (NAR&NAC).

Two houses were selected to satisfy each criteria and the samples were collected from bed room and living room area to represent the different environmental disciplines. Altogether 108 samples were collected for the measurements of household asbestos content. Google images of selected locations in each urban, sub-urban and peri-urban areas of Colombo District are given in Figure 1a, 1b and 1c respectively.

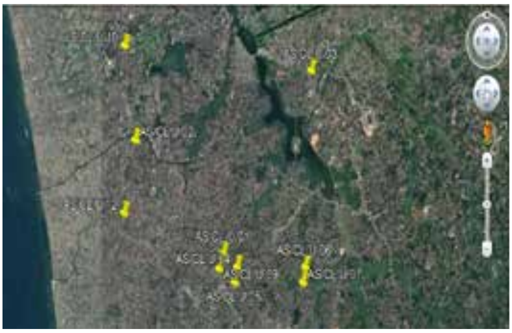


Figure 01(a): Selected locations in urban are

Figure 01(b): Selected locations in sub-urban areas

Figure 01(c): Selected locations in peri - urban areasareas

3.2. Collection of Samples

All samples were collected according to the standard method as the determination of asbestos and other fibres in air by Phase Contrast Microscope (PCM) stipulated by National Institute of Occupational Safety & Health (NIOSH 7400), America. The sampling flow rate of the pump and the sampling period was decided to comply to the test method. The special consideration was taken during the sample transportation to the laboratory to avoid the damaging the sample and also when removing the sample from the sampling setup without any disturbing to the sample.

3.3. Identification and Counting Chrysotile fibre levels

The fiber counting was done using PCM after the clearing and mounting process. The identification and counting of respirable fibre levels in the collected samples were done by using a Walton-Backett graticule (Type G22) with 100 ± 2 µm projected diameter circular area. The same procedure was repeated to cover all sample area (about 100 graticule fields) in according to the counting rules of the method. Then, the fibre density of the sample was calculated using the following equation.

$$E = \frac{(F/n_f)-(B/n_b)}{A_f}$$

Where;

E - Fibre density of the filter,

F/n_f - Mean fibre counter per graticule field

B/n_b - Mean fibre blank counter per graticule field

A_f - Graticule field area

Then, the fibre concentration of sample C, was calculated using the following equation

$$C = \frac{EA_c}{V*10^3}$$

Where;

C - Concentration of fibre (fi/cc),

E - Fibre density of the filter

V - Air volume sample (l)

A_c - Effective collection area of the filter (mm^2)

4. Results and Discussion

According to the PCM method, the quantitative working range of the method is 0.04 to 0.5 fiber /cc for a 1000 L air sample. The limit of detection (LOD) of the method depends on sample volume and quantity of interfering dust, and is <0.01 fiber/cc. if free of interferences. Therefore, calculated fiber concentrations levels in all locations are well below the LOD level of the method.

The fiber count and calculated fiber concentration in each location in urban, sub-urban and peri-urban areas of Colombo District are presented in figure 2.

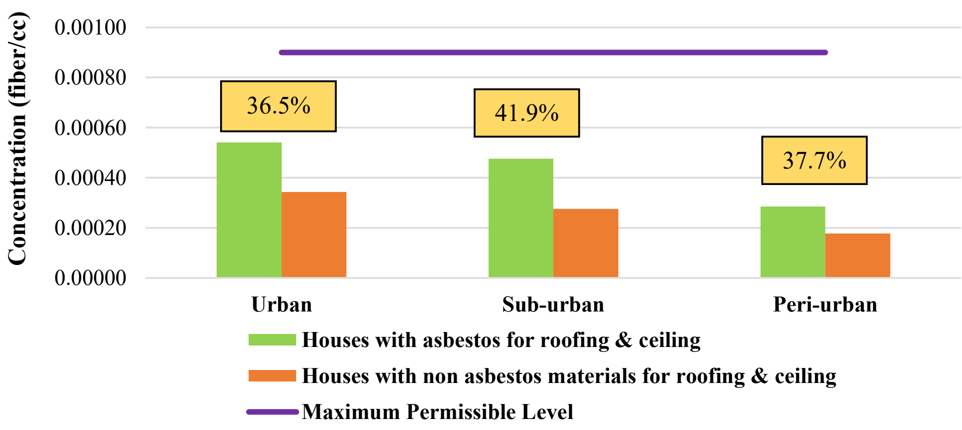


Figure 02: Variation of chrysotile fiber Concentration in different urban environmental conditions

The measured indoor chrysotile fiber concentrations in all households were below the exposure limits stipulated by US-EPA which is 0.0009 fibers/cc.

The variation of average indoor fiber concentration in urban, sub-urban and peri-urban areas is presented in figure 3.

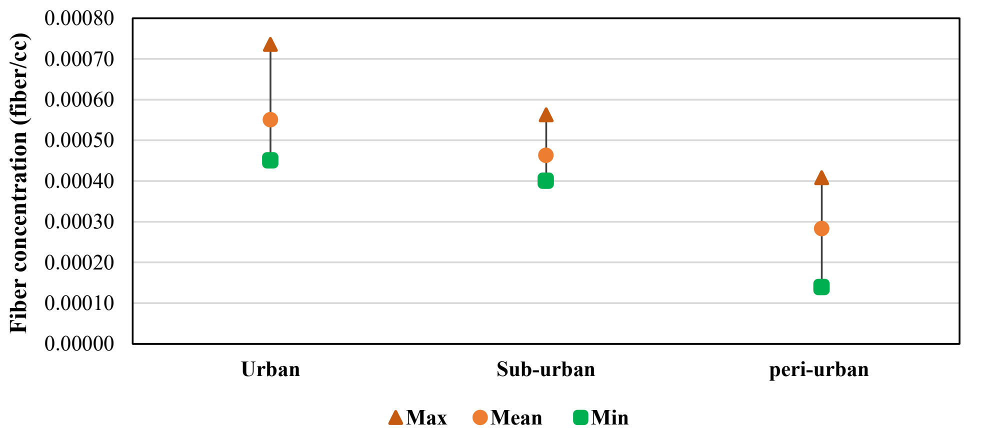


Figure 03: Variation of average indoor fiber concentration in different urban environmental conditions

According the analysis, the fiber concentrations are high in urban and sub-urban areas compared to peri-urban areas. This may be due to the high housing density in urban and sub-urban compared to peri-urban areas where the roofing is predominantly Asbestos cement sheets. It is further observed that the difference in fiber concentrations is only lightly low between urban and sub-urban areas although the housing density in the sub-urban areas are much lower compared to urban environments. The reason could be that the houses in the sub-urban areas are occupied by middle to low-income people where the finishing of the houses are relatively poor compared to urban houses. This allows unfinished roofs and ceilings exposed to higher weathering and decay compared to finished surfaces. Further, the ventilation condition in sub-urban houses is noticeably poor compared to urban houses considered for this study.

The study further indicates that the fiber concentration in the houses with asbestos for both roofing and ceiling or either roofing or ceiling was 36.5% higher than the houses with non-asbestos material in urban areas, by 41.9% in sub-urban areas and by 37.7% in peri-urban areas as indicated in figure 2.

5. Conclusion

The measured indoor chrysotile fiber concentrations in all households were below the exposure limits stipulated by US-EPA which is 0.0009 fibers/cc. In all cases the main source of Asbestos in the environment is asbestos-cement roofing sheets. In this case the release of fibres to the environment is minimized, since the fibres are essentially "locked" in the cement matrix. Asbestos cement products, therefore, do not usually pose problems for indoor air quality.

Factors such as renovation and repair, maintenance, external vibrations and destruction can considerably increase the emission of asbestos dust from existing indoor sources. Increased emission is also possible as a result of changes in temperature and reduction of humidity.

Unlike the levels of asbestos fibers in outdoor air, fibre concentrations in the air of indoor environments can always be related to their source, thus offering the possibility of modifying or removing the source of emission. As people live indoors most of the time the most relevant source of inhalation exposure will often be asbestos fibre concentrations in buildings.

Therefore, make the general public awareness on the safe use of asbestos containing product can reduce the indoor air pollution as well as can further minimise the health risk associated with the exposure to asbestos.

6. References

1. Lohrer, W. Asbestbelastete Innenräume - Analyse und Bewertung des Gefahrenpotentials [Asbestos exposed interiors - analysis and evaluation of risk potentials]. Staub, Reinhaltung der Luft, 43: 434-438 (1983).
2. Nicholson, W.J., et al. Asbestos contamination of the air in public buildings. Research Triangle Park, NC, US Environmental Protection Agency, 1975 (Final report, contract 68-02-1346).
3. Report of the Royal Commission on Matters of Health and Safety Arising from the Use of Asbestos in Ontario. Toronto, Ontario Ministry of the Attorney General, 1984, Vol.1-3
4. National Research Council. Asbestiform fibers: no occupational health risks. Washington, DC, National Academy Press, 1984.
5. Sawyer, R.N. Indoor air pollution: application of hazard criteria. Annals of the New York Academy of Sciences, 330: 579-586 (1979)
6. Asbestos Information Centre. (n.d.). Asbestos Related Diseases & Health Risks, Retrieved August 29, 2016, from Asbestos Information Centre: http://www.aic.org.uk/asbestos-related-diseases/
7. World Health Organization (WHO): Air Quality Guidelines for Europe, 2nd ed., WHO Regional Offi ce for Europe, Copenhagen 2000.
8. Claudia Ricchiuti, Andrea Bloise, and Rosalda Punturo, Occurrence of asbestos in soils: State of the Art, Department of Biological, Geological and Environmental Sciences, University of Catania, Corso Italia, 55, 95129 Catania CT, Italy

INNOVATION GEARED
Building Resilience

Flood Risk Analysis in Environmental Management of Solid Waste Dump Site: A Case Study of Karadiyana Controlled Waste Dump

WKN Chandrasena[1], DAJ Ranwala[2]

[1]Civil Engineer, National Building Research Organisation, Sri Lanka
[2]Hydrology and Hydro Modelling Specialist, Freelance Consultant

Abstract

A flood risk analysis was carried out as a preliminary requirement of the design approach for a large active solid waste dump site at Karadiyana in Sri Lanka. The main objective of this risk analysis was the determination of flood levels for various return periods to support decision making in the design proposals for rehabilitation of the existing waste dump. In the initial stage of the study, a spot level survey and a canal depth survey were conducted to identify waste dump heights and evaluate the capacities of existing drainage canal network. All sub catchments related to the study area were identified and formulated using Digital Elevation Model (DEM) and related information was obtained from ground surveys. Design storms for return periods of 5, 25, 50 and 100 years were developed, simulated using updated IDF curves and HEC HMS model was used to analyze catchment flows towards the waste dump. Model runs were carried out for several scenarios considering future developments. HEC HMS model outputs were utilized for HEC RAS 2D flood model to determine flood levels for different return periods. The model outputs were compared with a previous study conducted in 2003 and these were found to be compatible with the study. A worst-case flood level of 3.2 m MSL for 100-year return period was recommended for the design of rehabilitation works.

Keywords: flood risk, HEC HMS, HEC RAS, Karadiyana, solid waste

1. Introduction

Karadiyana controlled waste dump is a cluster - based waste disposal site, located in a wetland area in Thumbovila, Piliyandala within the Kesbewa Administrative Division of Sri Lanka (Figure 1). Karadiyana solid waste dump is the largest active solid waste dumpsite in Sri Lanka. It is located at the most downstream of the Maha Ela sub basin which is the largest drainage area of the Weras Ganga basin. Western Province Waste Management Authority (WPWMA), the authority regulating the dumpsite, intends to rehabilitate the dumpsite into an environmentally friendly waste dump. WPWMA requested National Building Research Organisation (NBRO) to propose a technical design for its rehabilitation work.

This controlled dump is functioned as the final disposal facility for several Municipal and Urban Councils. Currently, the dumpsite is managed by the Western Provincial Waste Management Authority (WPWMA). The extent of the land allocated for waste dumping is 25 acres (approximately 10 hectares). The daily intake for the dumpsite is about 550 MT of Municipal Solid Waste (MSW). Because of the high MSW deposition on elevated levels, the dump is reaching its maximum capacity and thus posing a risk of landslide and slope failures to surrounding residential facilities. However, WPWMA as the regulatory authority, wanted to rehabilitate the waste dump in an environmentally friendly manner through application of scientific approaches. In this regard, National Building Research Organisation (NBRO) was requested to develop a technical design for the waste dump rehabilitation works. A flood risk analysis was conducted to identify safe flood levels in the area surrounding the dumpsite as a preliminary requirement for the geotechnical design works.

Figure 01: a) Karadiyana waste dump b) Surrounded canal system

2. Assessment Methodology

The main objective of this study is to determine the safe flood levels for various return periods to help decision making process in the design proposals for the rehabilitation of the existing waste dump. Hence, following approach, shown in Figure 2 was applied for analysing the flood risk.

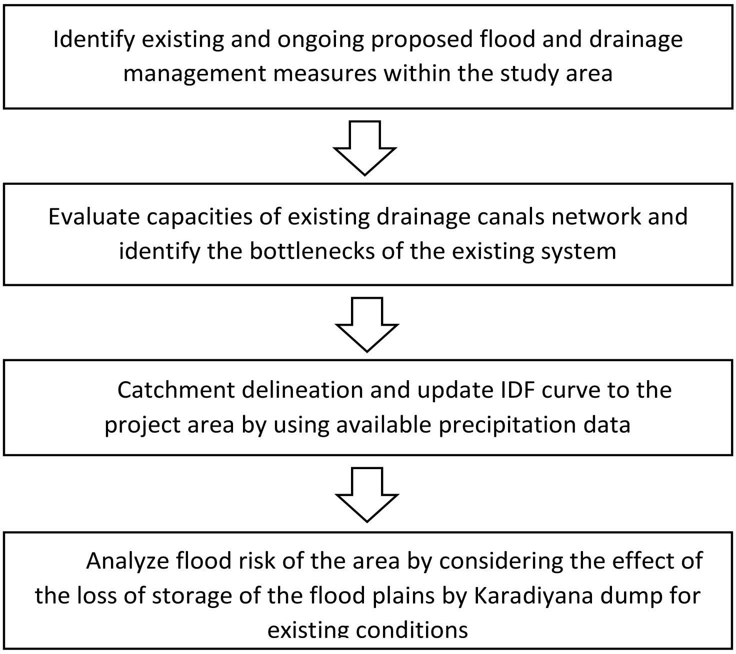


Figure 02: Flow chart for steps of the methodology

2.1. Identification of the prevailing drainage canal network and evaluation of drainage canal capacities

Prevailing drainage canal network and hydraulic structures were identified by field observations carried out by NBRO with the support of field experts and referring to drainage management plans for the vicinity of the Karadiyana waste dumping site under Weras Ganga Project by Sri Lanka Land Development Corporation (SLLDC).

During the field observations, it was identified that some drainage paths were abandoned and clogged by aquatic plants such as Water Hyacinth (Eichhornia crassipes) due to lack of maintenance. Canal bathymetry survey and a spot level survey were conducted separately to identify existing capacities of the drainage paths and to identify elevation profile of the waste dump area and its vicinity (Figure 3).

Figure 03a: Canal bathymetry survey

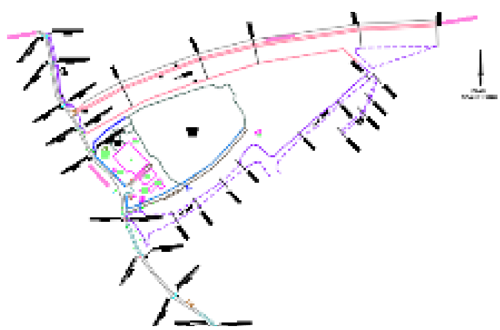


Figure 03b: Spot level survey

2.2. Catchment delineation and IDF curve update

All sub catchments of the study area were delineated using the Digital Elevation Model (DEM), information obtained from the LIDAR survey by the Department of Survey and the spot level data obtained from the study area. Sub catchment map of the study area and updated IDF curve of the Rathmalana area are presented in Figure 4 and Figure 5, respectively.

Design storms for the return period of 5, 10, 25, 50 & 100 were developed using the updated IDF curve. The duration used for design rain was 24 as the Time of Concentration (TOC) for the catchment was less than 24 hours.

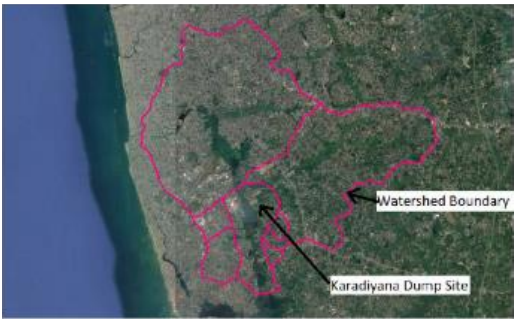


Figure 04: Catchment delineation for the Karadiyana dumpsite area

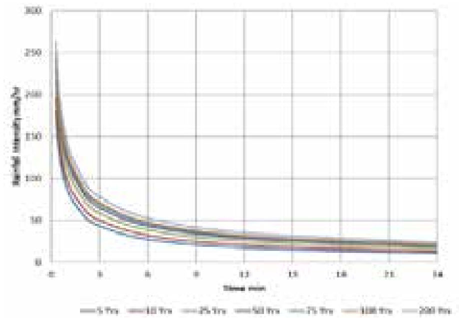


Figure 05: Updated IDF curve for Rathmalana

2.3. Hydrologic and hydraulic modelling

HEC HMS model of the US Corps of Engineers was used to analyse the catchment flow towards the dumpsite (Figure 6). Hydrological inputs from the HEC HMS Model were used for the HEC RAS 2D flood model to determine flood levels for different return periods i.e. 5 Year, 25 Year 50 Year and 100 Year. HEC RAS 2D modelling was conducted using the LIDAR DEM information, existing canal cross sections and spot levels. The terrain around the dumpsite and the canal network are represented in the hydraulic model schematization (Figure 6). The 2D hydraulic model set up is presented in Figure 7.

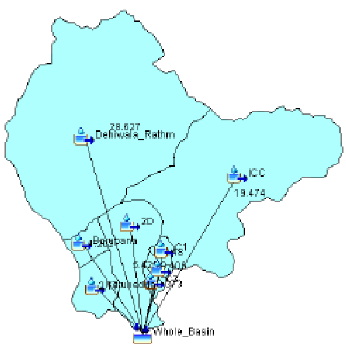


Figure 06: HEC HMS model schematization

Figure 07: 2D model set up of the HEC RAS model

2.4. Defining model scenarios with proposed developments by SLLDC

The basic model scenarios considered in the model are;

[1] 2D model with raw terrain without the canal improvement

[2] Canal dredged to -1m MSL

[3] Canal and Bolgoda Lake dredged to -1m MSL and a constant 50 m^3/s discharge from Madiwela south diversion canal

[4] 2D model with raw terrain without the canal improvement but with Madiwela canal diversion

[5] 2D model with canal dredged to -1 MSL and Madiwela canal diversion

Madiwela South diversion is a proposed diversion from Colombo catchment to Weres Ganga catchment through the main canal, which was recently rehabilitated and flows close to the dump site. The details of the possible inflow from the proposed diversion was obtained from SLLDC and according to SLLDC, 50 m^3/sec peak discharge will represent the worst case scenario as there are other solutions considered and if such solutions are successful the proposed diversion will not be implemented.

The model runs carried out for the above scenarios are presented in Table 1.

Table 01: Model scenarios tested

Return Period (Years)	[1]	[2]	[3]	[4]	[5]
5	✓	✓	✓	×	×
10	✓	✓	✓	×	×
25	✓	✓	✓	×	×
50	✓	✓	✓	✓	✓
100	✓	✓	✓	✓	✓

3. Results & Discussion

Safe flood levels were calculated considering all scenarios as shown in the Table 2. According to the computed flood levels, the worst-case flood level of 3.20 m MSL was recorded for the 100 - year return period in the scenario [4]. As per the computed flood levels shown in scenario [1] and [2], there is a significant difference observed between scenario [1] and [2] due to the result of canal dredging to -1m MSL. In addition, the previous study (The study on storm water drainage plan for the Colombo Metropolitan Region in the democratic socialist republic of Sri Lanka) conducted by Japan International Cooperation Agency (JICA) in 2003 has considered 5, 10, 25, and 50 year return periods for the present [A] and future [B] land use patterns as shown in Table 2 and flood levels had been calculated for the Maha Ela outfall in 2003. The lowest flood levels were recorded for the scenario [2] and there are no significant differences recorded for scenario [4] and scenario [5], indicating that there will not be any significant effect on canal improvements if the Madiwela canal diversion is implemented.

Table 2: Preliminary flood levels for the dumpsite

Return Period (Years)	[1]	[2]	[3]	[4]	[5]	[A]	[B]
5	2.21	1.04	1.40	-	-	0.93	1.06
10	2.44	1.29	1.58	-	-	1.00	1.12
25	2.67	1.58	1.82	-	-	1.08	1.17
50	2.90	1.76	1.99	3.08	3.07	1.12	1.21
100	3.07	1.93	2.13	3.20	3.20	-	-

[A] - JICA 2003 study for present (2003) land use at Maha Ela outfall (JICA study report March 2003, Volume II main report, Table 14.1)

[B] - JICA 2003 study for future land use at Maha Ela outfall (JICA study report March 2003, Volume II main report, Table 14.1)

Flood spread maps and flood velocity maps produced by HEC RAS 2D modelling are shown in Figure 8 to Figure 9.

Figure 08: Flood Spread Map for 5 Year Return Period for raw terrain without dredged canals [Present Condition]

Figure 09: Flood Spread Map for 05 Year Return Period for raw terrain with dredged canals [Future Condition]

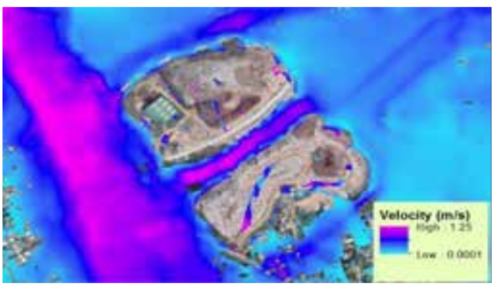


Figure 10: Flood Velocity Map for 5 Year Return Period for raw terrain without dredged canals [Present Condition]

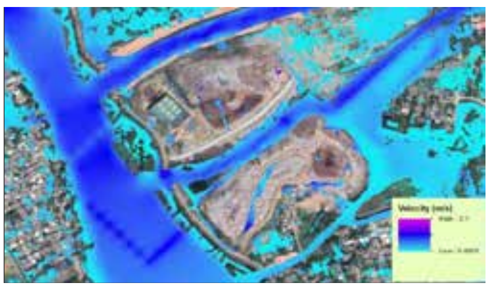


Figure 11: Flood Velocity Map for 5 Year Return Period for raw terrain with dredged canals [Future Condition]

Figure 12: Flood Spread Map for 100 Year Return Period for raw terrain without dredged canals [Present Condition]

Figure 13: Flood Spread Map for 100 Year Return Period for raw terrain with dredged canals [Future Condition]

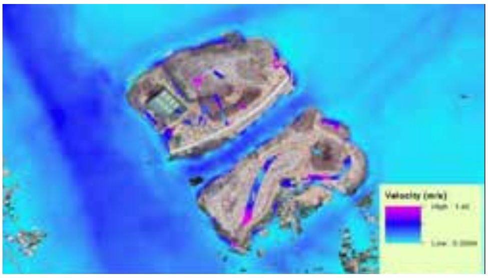


Figure 14: Flood Velocity Map for 100 Year Return Period for raw terrain without dredged canals [Present Condition]

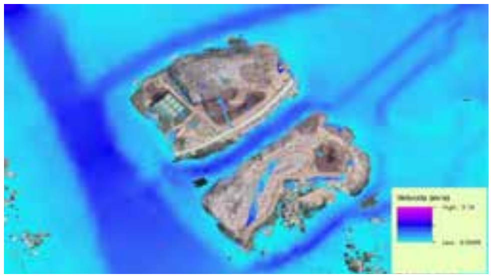


Figure 15: Flood Velocity Map for 100 Year Return Period for raw terrain with dredged canals [Future Condition]

4. Conclusion

In this case study, popular HEC HMS and HEC RAS hydrological and hydraulic modelling software were used to determine safe flood levels in the Karadiyana waste dump area considering future development scenarios proposed by SLLDC. Initially, the existing land use conditions were modelled, simulated and validated with JICA studies and related SLLDC flood studies to ensure the consistency and reliability of the output results. Then, future developments proposed by SLLDC were considered. While carrying out this study, it was observed that safe flood levels highly vary with the proposed Madiwela canal diversion and canals improvements (dredging to -1 m MSL). The most critical flood level (3.2 m MSL) was recorded for the scenarios [4] and [5] with Madiwela canal diversion.

5. Acknowledgements

The support extended by National Building Research Organisation, Western Province Waste Management Authority, and Sri Lanka Land Development Corporation are gratefully acknowledged.

6. References

1. Chow, D.R., Maidment V.T., and Mays, L.W., 1988, Applied Hydrology.
2. Hogg, W.D., Leytham, K.M., Neil, C.R., Sellars, C.D., Watt, W.E., Guidelines for Extreme Flood Analysis, Alberta Transportation, Canada, 2004, 1-9pp
3. Hydrologic Engineering Center (HEC), "Hydrologic Modeling System HEC HMS, User's Manual, version 3.0.1. U.S. Army Corps of Engineers, CA, 2006, 248
4. Institute of Hydrology (IH), "Flood Estimation Handbook (FEH) – Procedures for Flood Frequency Estimation", Institute of Hydrology, United Kindom, 1999
5. Japan International Cooperation Agency, The Study on Storm Water Drainage Plan for the Colombo Metropolitan Region in the Democratic Socialist Republic of Sri Lanka, 2003.

Exposure Levels and Seasonal Variation of Airborne Asbestos Fiber Concentration in Colombo City, Sri Lanka

NKPMM Perera[1] , HD Kumarapeli[1] , DMMR Dissanayake[1] , HDS Premasiri[2]

[1]Scientist, National Building Research Organisation, Sri Lanka
[2]Director, Environmental Studies & Services Division, National Building Research Organisation, Sri Lanka

Abstract

Exposure to airborne asbestos fibers leads to adverse health effects depending on the fiber concentration and exposure time. Chrysotile, white asbestos, is considered as the major type of asbestos commercially used Worldwide including Sri Lanka for manufacturing roofing and ceiling sheets. However, other types of asbestos fibers had been used in early days for commercial items which was discontinued from using due to their health risk. Not only during the manufacturing and handling process, asbestos fibers can be released to the atmosphere and people may be exposed to them even while using the end products.

This study was carried out to assess the airborne asbestos fiber concentration levels in selected environment conditions in Colombo City, Sri Lanka. The method used for the sampling and determination of airborne asbestos fibers is NIOSH Method 7400, Phase Contrast Microscope (PCM) stipulated by National Institute of Occupational Safety & Health. The sampling locations were selected to represent urban, suburban and rural areas and study was conducted in two monsoonal seasons. The study results indicate, airborne asbestos concentration levels in study areas were ranging from 0 to 0.0005 fibers/cc which were below the levels recommended by the European Agency for Safety and Health. Once the levels are interpolated as maps generated by ArcGIS software, it was identified that the asbestos fiber concentration levels in urban areas were relatively higher and high fiber concentrations were detected in North-East monsoon period than the South-West monsoon period claiming the wind pattern plays a major role in fiber dispersion.

Key Words: chrysotile, airborne asbestos, monsoon periods, spatial variation, wind direction

1. Introduction

Asbestos is a group of naturally occurring mineral silicate fibers of the serpentine and amphibole series. These minerals are formed by the combination of magnesium and silicon which provides the fiber a strong and a crystalline structure. Serpentine asbestos has curly fibers made up of sheets of crystals whereas Amphibole asbestos has needle-shaped fibers. Chrysotile fibers that belongs to the serpentine family has historically accounted for more than 95% of all asbestos used around the world. Amosite, crocidolite, anthophyllite, tremolite and actinolite belong to the amphibole series.

Chrysotile (white asbestos) is the most commonly used form among asbestos fiber types. It can be found abundantly in roofing materials, walls and floors of houses and other buildings. Manufacturing industries use chrysotile fibers in automobile brake linings, gaskets and boiler seals, and insulation for pipes, ducts and appliances.

Qualities of asbestos fibers such as resistant to heat, electricity and corrosion make this mineral useful for different industrial activities and certain manufacturers. Mostly, the asbestos fibers are used as an effective insulator and can be used in cloth, cement, paper and other materials in order to make them stronger and hence to improve the durability. As asbestos fibers in the micrometer range, there is a tendency for fibers to be in the ambient air (Indoor and Outdoor) and when these asbestos dust is inhaled or ingested by human beings, fibers can become trapped in the body permanently specially in the respiratory tract. Over the time, trapped asbestos fibers can effect on human body in various ways causing inflammation, scarring and eventually genetic damage.

In the past, the most commonly used forms of asbestos were chrysotile (white asbestos) and crocidolite (blue asbestos). Blue Asbestos has been banned in Sri Lanka since 1997, but white asbestos is still being used as roofing sheets all around the Country. Even though, there are few major asbestos roofing products producers in Sri Lanka, most abundant asbestos products are roofing sheets and ceilings. The Country had been using asbestos roofing sheets and ceilings since early 1960s in factory buildings and houses. But, according to the available data, Country had been imported asbestos materials in late 1990s up to now by an average quantity of 500-1,000 tons per year and the highest importation of asbestos was recorded in 2009. In 2009, Two million tons of asbestos were mined Worldwide. The Russian Federation was the largest producer with about 50% World share, followed by China (14%), Brazil (12.5%), Kazakhstan (10.5%) and Canada (9%). Sri Lanka imports asbestos mainly from Russia. In general, all the asbestos types are considered as dangerous while some types of asbestos are more hazardous than others. Supporting the concept of being hazardousness, the U.S. Department of Health and Human Services, the EPA and the International Agency for Research on Cancer classify all types of asbestos as cancer - causing substances.

In early days, raw asbestos was handled by the workers exposing them to fiber during the production of asbestos roofing sheets. With new technology, the handling of raw asbestos has been eliminated as the production has been automated. Even though the asbestos roofing sheets had been used in Sri Lanka for decades, not even a single case of asbestos - related lung cancer (mesothelioma) has been reported so far.

Recently, the Sri Lankan Government announced that asbestos would be banned in the Country from 2018 and this decision influenced scientists to conduct thorough scientific studies on asbestos materials in the Country to identify the actual situation and the impact to the society from asbestos materials.

Even though the major source of airborne asbestos fibers from roofing materials, a significant contribution is also coming from automobiles and automotive components. Certain qualities of asbestos fibers such as durability, insulation, heat resistance and fireproofing are used to manufacture automotive parts such as air hoses, gaskets, heat seals, automobile hoses, body construction, hood liners, brakes, insulation, clutches and clutch faces, mufflers, engine components, valve rings & etc. Therefore, movement of automobiles, repairing and services & replacing parts can be considerable sources of airborne asbestos fibers in areas where high traffic and service centers are existed [2] [3] [4].

Another aspect of asbestos fiber dispersion in the atmosphere is the meteorological and geographical factors in a particular area. Studies showed that the wind speed and wind direction resulted by seasonal wind patterns play a major role in dispersing airborne asbestos fibers [3] [4].

This study was done by the Environmental Studies and Services Division (ESSD) of National Building Research Organisation (NBRO) which is under the state ministry of Internal Security & Home affairs and Disaster Management. A comprehensive study was carried out by NBRO in 2016 to investigate certain sampling and analysis procedures were extracted from previous study to optimize the present study. The purpose of the study was to estimate the spatio - seasonal variation of air borne asbestos fibers within the Western Region of Sri Lanka. Lack of studies on airborne asbestos fibers in the Country also influenced to carry out this study in order to predict the current trend of fiber dispersion in one of the most urbanized and polluted Regions in the Country.

2. Methodology

The method used for the determination of air borne asbestos fibers in the atmosphere was Phase Contrast Microscope (PCM) stipulated by National Institute of Occupational Safety & Health (NIOSH 7400). To comply with the method, 25 mm, 3 - piece open-faced filter holder (Figure 1 and 2) fitted with 50 mm electrically conductive cylindrical cowl and mixed cellulose ester filter 0.45 µm pore size and backup pad was used for the sampling. Personal samplers were used to collect samples from the ambient air and the sampling program was done in the manner of representing urban, sub urban and rural areas of the City including Colombo mega polis area.

This study was carried out in the Colombo area (36 locations) to investigate the spatial variation of asbestos fiber concentration. Collected data was analyzed and interpolated using ArcGIS software to visualize the spatial variation. Since, the sampling program was carried out in two seasons (North-East and South-West monsoon periods), GIS maps were generated separately in order to compare the spatial variation.

Analysis was done using the ¼ part of the filter paper and the fibers were counted using Phase Contrast Microscope (PCM) after the completion of the clearing and mounting process. As per the PCM standard method, fibers in the sample were focused to clear vision to identify and count respirable fiber levels in the collected samples using a Walton-Backett graticule (Type G22) with 100 µm projected diameter circular area.

The fiber density of the sample was calculated using equation (1).

$$E = \frac{\frac{F}{n_f} - \frac{B}{n_b}}{A_f} \text{ ------------------(1)}$$

Where;

E - Fiber density of the filter,
F/n_f - Mean fiber counter per graticule field
B/n_b - Mean fiber blank counter per graticule field
A_f - Graticule field area

Then, the fiber concentration of sample C, was calculated using equation (2).

$$C = \frac{E * A_c}{V * 10^3} \text{ -------------- (2)}$$

Where;

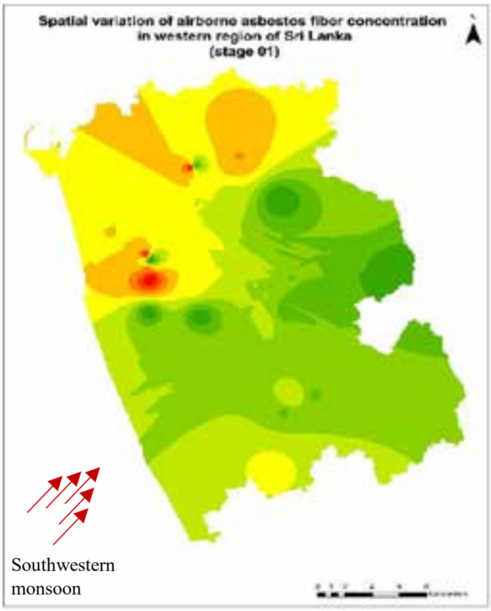
C - Concentration of fiber (f/cc)
E - Fiber density of the filter
V - Air volume of the sample (l)
A_c - Effective collection area of the filter (mm^2)

3. Results and Discussion

There are two clear monsoon seasons in Sri Lanka when considering the wind direction and rainfall. Those are North-Eastern monsoon period, operated from December to February and the South-West monsoon period, operated from May to September. Two sampling stages were carried out to represent the monsoon periods so that a comparison can be done according to the wind direction as asbestos fibers are considered as fine airborne fibers in micrometer (µm) range. Figure 1 and 2 show the change in asbestos fiber concentrations in the region according to the wind direction of each season Stage 1 represents the South-Western monsoon period while Stage 2 represents the North-Eastern monsoon period. Figure 1 & 2 clearly emphasizes the influence of wind speed and wind direction on the dispersion of airborne asbestos fibers over the monsoon period.

Even though the wind direction and wind speed are considered as major influencing factors in atmospheric asbestos fiber dispersion, other geomorphological factors can also affect the dispersion. Factors such as geographical features in the area, presence of high-rise buildings and automobile service centers, waste disposal methods and locations in the area and population density, etc. also affect the spatial variation of airborne asbestos fibers in a particular area.

The quantitative visualization of the spatial variation of airborne asbestos fiber concentration is shown below graphically (Graph 1). The figure 1 shows the increment of the fiber distribution within the selected area in stage 2 compared to the stage 1 as the stage 2 sampling program was done in North-East monsoon period. This also proves the influence of wind direction upon the airborne asbestos fibers to distribute in the ambient air.



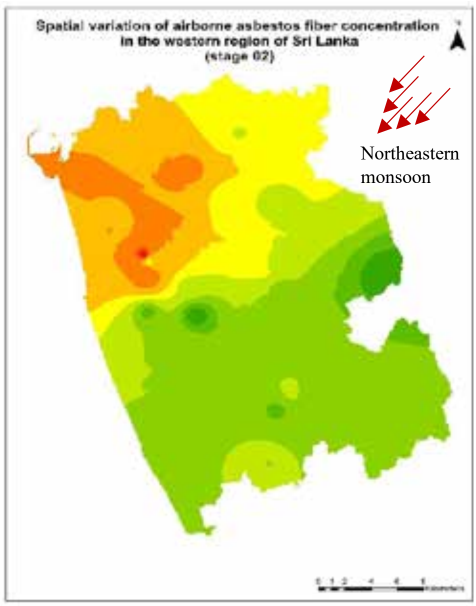


Figure 01: Stage 1 - Spatial variation of airborne asbestos fiber concentration in the Colombo of Sri Lanka during South-Western monsoon (May to September)

Figure 02: Stage 2 -Spatial variation of airborne asbestos fiber concentration in the Colombo of Sri Lanka during North-Eastern monsoon (December to February)

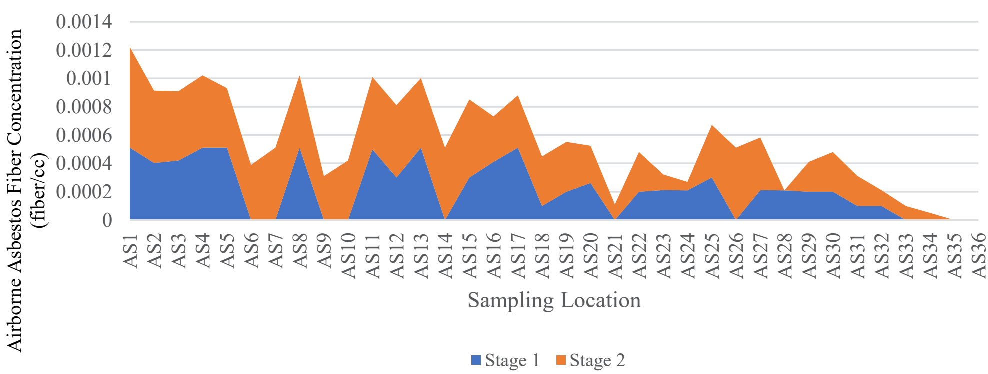


Figure 03: Variation of Airborne Asbestos Fiber Concentrations in Stage 1 & 2

4. Conclusion

It is a proven factor that airborne asbestos fibers are dangerous to human health in many ways. The main objective of this study was to identify the spatial variation of airborne asbestos fibers in the Colombo area. The sampling locations were selected to represent urban, suburban and rural areas of the Western Region and two programs were carried out to cover the monsoon periods as well. The results indicate a clear image of how airborne asbestos fibers vary with demographical features as well as monsoon periods.

Airborne fiber concentrations values emphasize the range of fiber quantity in a particular area and all concentration values were well under the guideline value of NIOSH standard 7400, Issue 3 which is 0.1 fiber/cc. Measured concentration levels were ranging from 0 to 0.0005 fibers/cc.

Even though there are several influencing factors, data interpolation which was done by ArcGIS application clearly shows that wind speed and wind direction play a major role for airborne asbestos fibers to disperse through the selected area.

5. References

1. Mokhtari M, Jafari N, Ebrahimi A, Mohammadi A, Abdolahnejad A, Hajizadeh Y, Niknazar H. Assessment of airborne asbestos fibers concentration in Yazd city in summer 2015. Journal of Environmental Health and Sustainable Development (JEHSD). July 2016. Pages 1-7.
2. Mokhtari1 M, Jafari N, Mohammadi M, Hajizadeh Y, Ghanbari R, Nemati S, Abdolahnejad A. Temporal and spatial trends of airborne asbestos fiber concentrations in the urban areas of Yazd, Iran. International Journal of Environmental Science and Technology. June 2018.
3. Kakooei H, Yunesian M, Marioryad H, Azam K. Assessment of airborne asbestos fiber concentrations in urban area of Tehran, Iran. Air Qual Atmos Health (2009) 2:39–45.
4. Fathabadi M K F, Abdolahnejad A, Teiri H, Hajizadeh Y. Spatio-seasonal variation of airborne asbestos concentration in urban areas of Shiraz, Iran. International Journal of Occupational and Environmental Health. January 2018.

INNOVATION GEARED
Building Resilience

Zero Waste Management Plan to National Building Research Organisation with Special Reference to Solid Waste

SAMS Dissanayake[1], SV Dias[2], PSH Elvitigala[3]

[1] Senior Scientist, National Building Research Organisation, Sri Lanka
[2] Former Director, National Building Research Organisation, Sri Lanka
[3] Engineer, National Building Research Organisation, Sri Lanka

Abstract

The operation of National Building Research Organisation generates 18 types of waste from common Municipal waste to hazardous waste. Being a responsible organization, in order to achieve sustainable management of resources the organization management intends managing its waste in a sustainable manner through a systematic waste management plan.

Three concepts were used in the study. (i) The zero-waste approach (ii) Systems thinking approach and (iii) Life Cycle assessment approach. All waste streams identified were mapped first using descriptive waste flow diagrams portraying the fate of each waste type step by step from the generation to ultimate disposal. Then, fate of waste at onsite and off-site management was also evaluated with the objective of understanding quantity of material recovery, composting and end of life in waste dumps. Both qualitative and quantitative methods were used in the assessment process.

It was identified through the analysis that i) most of the waste management strategies operational both on-site and off-site operate as isolated entities and hence overall system approach is lacking ii) There are still untapped opportunities in the waste recovery options requiring further improvement such as considering giving priority for recognized highly efficient waste material recyclers with good pollution control in selling waste. iii) Pay special attention to reduce/recover hazardous waste such as batteries and generation of e-waste by promoting on-site alternative options for use of rechargeable batteries, use of sensors instead of chemicals for testing, procure durable equipment from reliable suppliers with good after sales services, procure toners and cartridges form agents who accept the empty cartons for recycling are needed iv) Establish a National level hazardous waste management strategy and a facility to prevent those ending in landfills are also required.

Key words: zero-waste, system thinking, life cycle assessment

1. Introduction

A generation ago, many Cities around the World did not have comprehensive solid waste management programmes. Organic waste was fed to animals and packaging waste hardly existed. But today, due to the growing population, rapid urbanization and economic development, managing trash has become one of the most pressing issues faced by the planet. In Sri Lanka with no exception, population growth and per capita income growth have raised the issue to a different scale (with a disproportionately heavy generation of waste) and technological complexity (with changes in the composition of waste). Colombo as the hub City for trade and business, daily generates about 700 tons of garbage within its City limits. Waste generation is comparatively high within the Colombo City due to high population density, businesses, non-resident population and the residents' economic status. Off-site disposal is the commonly practiced waste management strategy in the City and today it is a burning issue due to reasons inherent with urban solid waste management. Waste reduction at source is a promising solution to manage waste due to benefits it provides such as reducing the cost for raw materials and waste management and reducing the land requirement and environmental issues associated with off-site disposal.

The National Building Research Organisation (NBRO) is located within the Colombo Municipal Council (CMC), in a 3400 m^2 land plot. The organization offers research, technical and commercial testing services to the state and public sector. Apart from administrative and financial units there are three testing laboratories. Overall staff strength is around 150. The operation of the organization generates a wide range of solid waste from common municipal type to hazardous waste.

Three concepts were used in the study. (i) The zero-waste approach (ii) System thinking approach and (iii) Life Cycle assessment approach.

1.1. Zero waste concept

Zero waste concept is a very ambitious visionary concept where the primary objective is to ensure that all resources (materials, energy, manpower) used in the product, service or process life cycle are used in a maximum possible efficiency while minimizing the amount of materials sending to landfills, releasing to environment & piling up in waste yards or sending to incineration.

The concept is yet a new discipline to Sri Lanka. Many local businesses on product manufacturing, services and processes still follow the conventional approach along with few options (5S system) of reuse & recycling without considering overall zero waste management approach and systems for resource optimization, waste generation reduction, and pollution control while losing many valuable opportunities to reduce the amount of waste generating from their respective processes.

In the zero-waste approach, every effort is made to reduce consumption of materials, energy and waste, and hence zero waste can be considered as the backbone for resource and environmental sustainability of any man made system. Accordingly, in the zero-waste approach the system (product manufacturing, services, processes) is designed, built and operated with continuous improvement ensuring,

i. Optimum resource (materials, energy, manpower) utilization,
ii. Minimum waste in landfills
iii. Minimum impacts on the environment and
iv. Maximum productivity.

1.2. Systems thinking

Systems thinking is a way of thinking used to address complex and uncertain real-World problems. It recognizes that the World is a set of highly inter connected technical and social entities which are hierarchically organised producing emergent behavior.

1.3. Life cycle approach

It is an assessment that analyses flow of resources in system from extraction of raw materials, manufacturing, distribution, use and end of life in terms of (i) Material consumption & efficiency, (ii) Energy consumption (non-renewable vs renewable), (iii) Environmental impact (global warming potential and environmental pollution & damage), and system productivity

Life cycle assessment was originally based on cradle to grave assessment; i.e., Assessment of systems from extraction of materials to end of life. Applied on conventional systems in which the end of life is often in a landfill or a waste yard where

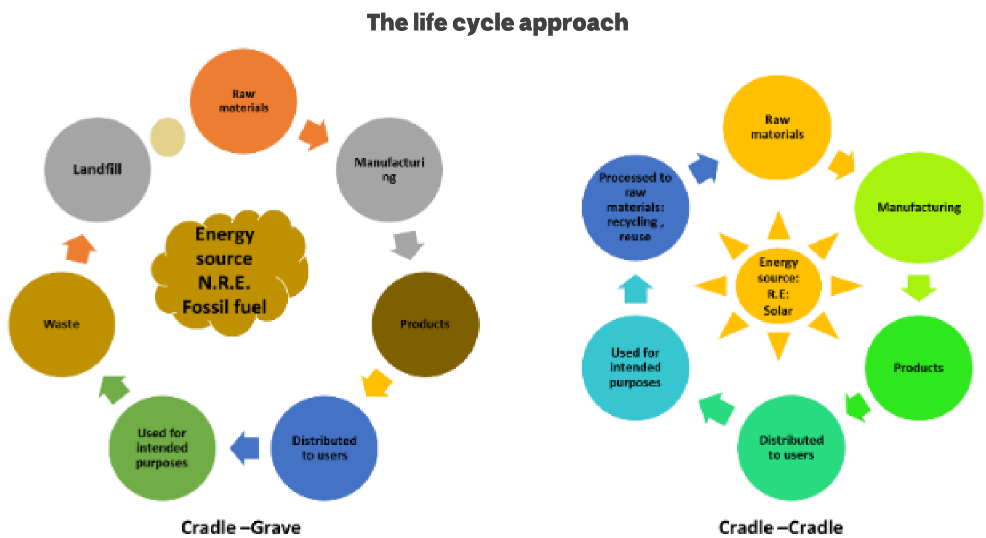


Fig. 1 Crade to Grave System & Cradle to Garve System

the system is a linear system where the system technology is very much conventional without systems thinking of sustainability integrated (Figure 1).

Cradle to cradle assessment is based on circular system thinking, where material and energy flow similar to that of a natural ecosystem are used in the assessment (Figure 1).

This paper discusses the scientific approach used in the evolution of waste management system of the organization and the province, strengths and weaknesses of current waste management system and suggestions to system improvement.

2. Objective

Being a responsible organization to achieve sustainable management of resources, the organization's management intends to manage its waste in a sustainable manner through a systematic waste management plan by:

- Reducing waste of raw materials/resources through 3R principle
- Minimizing the quantity of waste sending to open dumps
- Ensuring safe disposal of waste with minimum harm on the environment
- Suggesting alternative residue waste management options to avoid waste entering landfills
- Reducing costs for disposal of waste
- Generating revenue from waste

3. Methodology

Three concepts were used in the study; (i) The zero-waste approach (ii) System thinking approach and (iii) Life Cycle assessment approach. The study covers mainly the solid waste management system within the NBRO premises and partly the off-site management systems. All waste streams identified were mapped using descriptive waste flow diagrams. A waste inventory was prepared for all waste types including quantity of waste generated, recovered and disposed. Then fate of waste at off-site management was also evaluated, with the objective of understanding quantity of material recovery, composting and end of life in waste dumps.

During the study, both qualitative and quantitative methods were used to gather information and data. The different types of waste generation within the premises of NBRO were identified through the observation (office areas, open areas and the laboratories). Interviews and in-depth discussions were conducted with selected officers (supervisor janitorial service and store keepers) who are involved in solid waste removing from NBRO. To gather information on offsite solid waste management Colombo Municipal Council was consulted.

4. Results and Discussion

4.1. Waste stream and quantities

The analysis revealed that the operation of NBRO generates 18 waste types consisting highly bio degradable waste, slow to non-bio degradable waste and hazardous waste. Table 1 presents the 18 waste streams and estimated waste quantities.

4.2. Waste stream mapping

Waste stream maps were prepared for all waste streams. Waste stream map prepared for food waste is shown in Fig 2. This map portrays the fate of each waste type step by step from the generation to ultimate disposal; generation, collection, reuse, recycle, removal, ultimate disposal and environmental releases.

Table 01: Waste stream and waste quantity

Waste stream	Amount/ annum	Waste stream	Amount/ annum
1. Food waste	1400 kg	10. Battery waste - Zinc -carbon alkaline battery i. Lithium batteries ii. UPS of computers iii. Automobile batteries	 40 No 8 No 2 No
2. Garden waste	20 m^3	11. Obsolete furniture	24 No
3. Paper waste	15 m^3	12. Obsolete equipment & E-waste	20 No
4. Cardboard	10 m^3	13.Maintenance waste	32 No
5. Polythene/ plastic/ Pet bottles	80 kg	14. Glass	72 kg
6. Soil from testing lab (tested+ untested sample)	24,240 kg	15. Automobile waste	21 No
7. Building material from labs (tested + untested samples containing steel, concrete cubes, cement, and sand)	7200 kg	16. Washroom waste	6 m^3
8. Obsolete chemicals	2 kg	17. Empty toners and cartridges	72 No
9. Electronic waste	116 No	18. Water test materials from Env. Lab Sample wastes and spent chemicals	72 kg

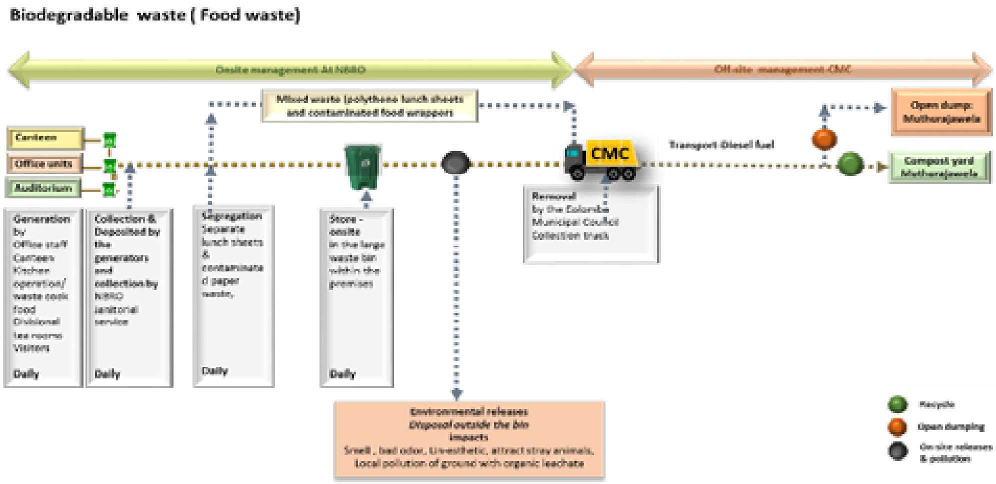


Figure. 02: Waste flow diagram -Food waste

4.3. Analysis of waste reduction efforts using 3R principle

4.3.1. On-site waste reduction at source

The NBRO practices waste generation reduction efforts by reducing the material consumption for certain waste types. Out of 18 major solid waste types a considerable waste reduction effort is practiced by controlling material consumption for five wastes; Paper, Toners and Printers, UPS batteries, Plastic & Polythene and chemicals (Table 2).

Table 02 - Waste generation reduction efforts by reducing the consumption

Waste type	Waste generation reduction effort by reducing the material consumption
1. Paper waste-good quality	i) Use of electronic media as a communication mode ii) Use of soft copies for editing & reviewing of documents. iii) Use of soft copies for literature searching & document archiving iv) Reuse one side printed paper for draft documents printing v) Keep track of records for paper usage
2. Plastic & polythene waste; office, canteen, labs	i) Organization provided lunch boxes free of charge for all staff to reduce the use of lunch sheets ii) use of pet bottles, lunch sheets, polythene is discouraged within NBRO
3. Electronic/IT waste	i) Provided central all in one built in facility photocopier, printer, and scanner for each division for all purposes. ii) Individual printers were given only for restricted purposes Number of printers, toners and cartridges reduced.
4. UPS Batteries	i) A decision has been taken to provide Lap-tops instead of desk -tops for all scientists and other staff officers. (This eliminated the requirement of UPS to a greater extent)
5. Old chemicals form environmental lab	i) Purchasing quantities were reduced and now on demand basis, some chemical-based test methods were replaced by sensor-based instruments

4.3.2. On-site reduction of waste by reuse and recycle efforts

On-site re-use and recycling of waste is practiced for 6 wastes out of 18 waste streams. Most of these practices are promoted by the management & the staff of NBRO. As a welfare service, employees are encouraged to take - home the unusable materials either free of charge or at a nominal rate (Table 3).

Table 03 - On-site waste reuse & recycle efforts

Waste type	On-site waste reduction efforts Reuse- recycle (description)
1. Paper waste-good quality	i. Reuse one side printed paper for draft documents printing, ii. Obsolete papers are collected and sold off for preparation of bags, wrappers etc.
2. Cardboard waste-good quality	i. Cardboard packaging is separately collected and sold for recyclers ii. Some cardboard boxes are used to store, documents, samples, and taken to home to be used to store items
3. Glass	Some chemical solvent bottles are reused after cleaning to store chemical reagents and samples
4. Waste test material from Material lab	The sand, aggregates, cement, tested concrete blocks, steel scraps are given to NBRO staff at a very nominal rate for domestic construction work, some materials are used for masonry works at NBRO premises
5. Old office furniture wooden, steel, plastic, MDF boards	Staff of NBRO is allowed to purchase old furniture. After minor repairs the staff can use them at home.
6. Electronic/IT waste	NBRO employees are allowed to purchase old version computers, printers and telephones at a nominal rate at the auction before selling to outside private collectors

4.4. Off-site management of highly bio degradable organic waste (food waste and degradable garden litter)

The Provincial & Local authority level efforts to effective recycling and reuse with respect to highly bio degradable organic waste is commendable in CMC area. The CMC is very much particular in high level of segregation of highly bio degradable waste (this includes food waste and degradable garden litter). According to the sources 80% of the organic waste is collected by the CMC and sent for composting at organic waste composting facility at Kerawalapitya in Muthurajawela marsh.

4.5. Off-site management of other categories of waste

Off-site waste reduction by reuse and recycling is a revenue generating activity. Several private sector vendors engage in this activity. This includes collection of good quality paper waste, clean cardboard, clean polythene, plastic, pet bottles, plastic cups, all recyclable plastics in equipment, furniture and etc., all forms of smeltable metals (iron & Cu), electronic, electrical items with extractable semi-precious metals such as ; Pb, Cd, Ag, Gold, Pt etc. and recyclable batteries, old tyres etc.

In the case of NBRO waste pertinent to above, several parties are involved in the business. Many parties engage in collection of waste and selling it to recyclers. In the case of tyres and automobile batteries the service agents collect the items and send them for tyre and battery manufacturers.

Figure 03: Percentage Reuse, Recycle & send to landfills

4.6 Percentage Reduce, Recycle, Reuse and dispose to landfills

Except food waste, garden waste, cardboard, and building material lab waste, certain other waste still does not go through re-use or recycling and certain amounts are end up in landfills. This is 100% for contaminated papers and waste test samples of Soil testing lab & Environment lab, Lithium batteries and Washroom waste (Fig 3).

4.7. Analysis of on-site and off-site management system efficiency

4.7.1. On site facilities

In general, removal of waste is systematically and timely done. However, piling up of waste is happening depending on the demand, nature of the operation of NBRO labs and poor on-site management practices. Limitation of space is a crucial issue at NBRO, hence on-site management of waste has several constraints, especially with respect to lab waste & final storage of waste.

Figure 04(a): segregated garden litter

Figure 04(b): Segregated glass waste

Soil testing lab and the Materials lab have no sufficient space to store waste test materials. Some aggregate materials get washed off and end up in drains and obstruct their smooth conveyance. Also, some of the unserviceable items too have to be kept outdoors until removed by the annual auction. The hazardous chemical waste generated by the laboratory operation are being collected and stored on-site as there is no hazardous waste disposal facility to receive these wastes.

Management of highly bio-degradable food waste is practiced at very high efficiency where both segregation at source, collection by the CMC and composting by the Waste Management Authority is very effective. Polythene & plastic materials, Glass, Paper & cardboard, Metals (Iron, Aluminium, Copper, Lead, bronze), Reusable textile waste, Coconut shells, E-waste & etc are also segregated at source, reused, and sent for recycling via various parties such as CMC and private recyclers. This is efficiently operated as a business. Automobile waste such as tyres, batteries are sent for recyclers by the service agents. Construction based waste test material such as sand, steel, cement, metal aggregates and test bricks etc are also given to office staff to be used in their domestic construction works.

4.7.2. Offsite solid waste management facilities

Segregation at the collection is mandatory for food waste and other highly bio degradable waste. These wastes are composted. Segregation of other non-bio degradable waste is also done at the collection by the CMC collectors.

4.7.3. Collection of waste-by-waste recyclers

According to Central Environmental Authority, Colombo District has 65 registered waste collectors, recyclers, and exporters. Majority of them collect, recycle and export glass, paper, cardboard, clean polythene & plastic, metals (iron, Al, Cu, Brass, Tin) and e-waste to extract metals, plastic & etc. This is a revenue generation activity for Polythene & plastic materials, Glass, Paper & cardboard, Metals (Iron, Aluminium, Copper, Lead, Bronze etc.), reusable textile waste, coconut shells & e-waste.

4.7.4. Management of clinical waste

Clinical waste in the Colombo Municipal area is collected separately and incinerated. However, there are complaints regarding the performance of this system.

4.7.5. Hazardous waste management

There is no separate disposal facility for hazardous waste in Sri Lanka. A Cement factory at Puttalam District accepts certain categories of hazardous waste and they incinerate the waste in their cement kiln. The kiln emissions are controlled by a well-maintained electrostatic precipitators and wet scrubbers

4.7.6. Kerawalapitiya Waste Park:

This waste park is located in the Muthurajawela mash in Kerawalapitiya and has three main components.

a. A compost yard
b. Temporarily mixed waste dump with partial pollution controls until Aruwakkalu land fill site is operated
c. A waste to energy plant under commissioning

5. System improvement options - From Cradle - Grave to Cradle - Cradle

In the NBRO study, the analysis of Material flow pathways and waste streams showed several commendable efforts on waste reduction through Reduce-Recycle & Reuse both on-site and off-site. But these are operated as individual isolated material flow paths and system approach is absent throughout the process. In the system approach, these can be effectively integrated towards achieving zero-waste.

The material flow and control in natural systems is governed by several factors. Therefore, it is important to recognize them and apply to man-made systems. Accordingly, in man made systems number of important aspects are recognized as core subjects requiring interventions in the implementation of zero waste system approach. Table 4 presents the comparison of factors in the two systems.

Table 04: Comparison of Natural Ecosystem and manmade system

Natural Ecosystem	A man-made system
I. Nature's governing rules for ecosystems	I. Policy & regulations
II. Nature's ecosystem plan for material flow	II. System planning & designing
III. All-natural resources, and energy	III. Investments, Resources and facilities
IV. Food webs	IV. Network of processes
V. The trophic status	V. Operational hierarchies
VI. Different specie with defined obligatory roles	VI. Diversity of actors with skills
VII. Ecosystem process technology for flow of materials	VII. correct process technology
VIII. Natural mechanisms	VIII. Implementation mechanisms
IX. Food back loops and dynamic equilibrium	IX. Operational controls
X. Continuous cycling of materials	X. System continuity
XI. All material cycles, O2 cycle, C Cycle, N Cycle, Hydrological Cycle	XI. Linking with external cycles

In the NBRO case study an attempt is made to align waste management of NBRO through Cradle-Cradle approach by mimicking the processes in natural ecosystems. We consider that this can be applied to any material flow process as indicated in the table 5.

Table 05: The aspects to be considered and system approach Zero waste planning for NBRO

Aspect	Action
1. Policy & regulations	NBRO to develop its zero-waste policy, norms and guideline towards achieving zero waste, using renewable energy sources, keep on-site environmental releases zero, & sending of waste to landfill is reduced over time
2. System design & planning	Based on this conduct assessments, develop systems designs and plans to achieve the objectives
3. Networking of processes	Each element in the system is considered as important and interdependent. These should be identified, and necessary linking should be made between the elements and flow paths
4. Investments, resources & facilities	Prepare a time bound financial plan with capital and recurrent investments, resources and facilities
5. Correct material process technology	Critically review available technology in material flows and revise the technology to achieve expected targets as planned
6. Management organization, Operational hierarchies, diversity of Actors with skills	Map the required operational hierarches, Identify and appoint actors with skills to perform the task. Develop the skills to ensure competency in performing dedicated tasks
7. implementation mechanisms (action plans)	Develop action plans & implementation mechanisms, identify resources and facilities required, and implement the system
8. Operational controls	Monitor to evaluate that the systems are operated as planned, or required further improvement etc. through continuous monitoring to ensure system consistency
9. Ensure system continuity. from NBRO-other Institutions	Integrate the institutional system with Local, Provincial & National services related to waste management

5.1. Derive System improvement options From Cradle – grave to Cradle – Cradle

The proposed cradle to cradle system approach for paper use at NBRO is shown in Figure 5. This system could be used not only for waste but also for all the resources consumed inside NBRO. By understanding and analysing the resource streams or waste streams and identifying the opportunities to apply cradle to cradle approach, incorporating the systems thinking into the NBRO culture Zero waste management could be achieved.

1. Paper consuming activities in NBRO

1. Testing services
   Client details, invoices
   Information on samples & testing
   Data & draft report editing
   Final report
2. Project reports
   Literature
   Draft report editing
   Final report (no) of copies
3. Staff details (administration)
4. Inventory control
5. Financial operations
6. Internal memos & meeting minutes
7. All Records

2. Technology & facilitation

1. Use correct paper type for the purpose
2. System digitization
3. Networking
4. Data bases and archives
5. Online systems
6. Only final reports are printed on paper
7. One original to be issued for reports, others are given as soft copies
8. Sharing information, document reviewing etc thru share folders
9. All circulations on meetings, minutes and memos through on-line systems
10. All records are digitized with access control
11. All obsolete documents send for recycling

3. Skill hierarchies Actors and skills & facilities

1. IT scientists, Technical staff with IT competency, data entry operators
2. Lap top computers, Network systems, Data sharing systems, software, Internet facilities
3. Centralized printing facilities
4. All units are operated with solar power
5. Ensure the systems is operational without failures

4. Monitor and control

1. Purchase of paper-reduced
2. Entergy consumption for IT network operation: monitored and optimized
3. Printers: number reduced
4. Toners: number reduced
5. Spent toners & cartridges sent to recyclers: ensured
6. Waste paper generation: reduced
7. Paper segregation: ensure that it is very good
8. Number of draft copies produced: reduced
9. Paper reuse: encouraged, increased
10. Paper contamination: prevented
11. Paper storages: properly established
12. Sending to recyclers: ensured
13. All records & data bases: Digitally Archived and updated
14. Security & safety controls: ensured
15. All obsolete documents: to be send for recycling: Ensured
16. Staff acceptance: ensure it is very good
17. Ensure that outside agencies linked are with satisfactory level of green approaches

5. Linking with external systems for system continuity

Establish environmentally sustainable operational link between NBRO –and outside entities

Raw materials: Paper

1. Use papers from manufactures who use recycled papers
2. Select suppliers who transport goods using hybrid or electric vehicles

Equipment & facilities

Select reputed durable equipment with green certification, long year warranties, who accept worn out spare parts, accessories and consumables for reuse & recycling, undertake services and repairs

Paper recycling

1. Select reputed recyclers who recycle papers from the registered list of Central Environmental Authority
2. Review the recycling procedure to ensure that facility is operated respecting stipulated environmental quality norms
3. Recycling processes use renewable energy sources, eg: Solar power, Hybrid vehicles or electric vehicles for transportation
4. Ensure that all generated paper is send for recycling

Figure 05: Proposed Cradle to Cradle System approach for paper use at NBRO

6. Conclusion

This study aims to find out how far the implementation of the concept of Zero Waste in solid waste management in NBRO. The concept of Zero Waste is to minimize waste generation so that less waste is wasted to the land fill targeting Cradle to Cradle approach. This is so as not to waste resources and prevent environmental damage. This can be achieved by Policy & regulations, System design planning, networking of processes, correct material process technology, identify operational hierarchies and Operational controls. Integrating the institutional system with Local, Provincial & National services related to waste management is vital to make the plan successful.

7. Acknowledgement

The authors wish to thank Dr. Sarath Mataraarachchi - Senior Lecturer: Built Environment New South Wales University, Sydney, Australia and Mr. Talebul Islam-Strategic Waste Management Planner, Waste Services Contract Manager, Irrigation & Water Management Researcher, Australia for the guidance given during the online course on sustainable infrastructure for NBRO.

8. References

1. "Zero Waste International Alliance". zwia.org.," [Online].
2. "INCOSEUK, "What is Systems Thinking?" 2010," [Online].
3. R. &. J. L. &. Y. M. &. C. J.-Y. Freeman, "Systems Thinking and System Dynamic to Support Policy Making in Defra," 2014.
4. "Solid waste management plan for colombo metropolitan area," [Online]. Available: http://www.sundayobserver.lk/2018/10/21/news-features/long-term-solution-colombo%E2%80%99s-waste-disposal-aruwakkalu-comes-rescue.

Analytical Approximation of Micro Pellet Dispersion Along Western Coast from the Explosive Fire Erupted in Mv X-Press Pearl Cargo Ship –Tool to Assist in Beach Restoration Works

RRD Ruhunuge[1], SAMS Dissanayake[1], PD Liyanaarachchi[1]

[1]Senior Scientist, National Building Research Organisation, Sri Lanka
[2]Scientist, National Building Research Organisation, Sri Lanka

Abstract

Micro plastics (size less than 5 mm) are considered as the most significant pollutant in the marine environment Globally. The fate of micro plastics in the environment is particularly important as they may be accumulated in the biological chain. Micro plastics may have a high adsorption capacity to pollutants. The micro plastic or nurdles, that fell overboard during the incident of fire erupted in 20th May 2021 on the Singapore-registered MV X-Press Pearl about 9.5 nautical miles North-West of Colombo, have spread with the ocean currents, carpeting beaches along the Western coast posing a serious beach pollution and damage to marine life. The incident was recorded as one of catastrophic chemical-disasters happened in the World from ship fires. In this study the micro plastic contamination in the beach sand was studied from Negombo to Chilaw. Micro pellet sampling in the affected beach was done in 4 sampling events; 28th May, 11th June, 23rd July and 14th September 2021 covering a period of 3.5 months. Samples were collected from seven locations along the Negombo to Chillaw coast covering approximately 25.6 km stretch. The total mass of accumulated micro plastics per square meter on each sampling event was estimated gravimetrically. The accumulation of micro plastics along the coast is not uniform due to number of factors pertinent to deposition (current behavior, morphology and bathymetry) and the wash-off of pellets back to sea. Therefore a mathematical polynomials was derived to estimate the total accumulated micro plastic quantities and rate of accumulation along the entire beach stretch. A third-order, exponential, and power polynomials were selected considering the non-uniformity of deposition characteristics at different sampling points. The derived trend lines were fitted with the measured mass of micro plastics in the selected sampling points for 4 sampling events covering a period of 3.5 months. As per the derived polynomials and their integrals, the total mass of accumulated micro plastics were 0.19, 0.93, 0.87, and 1.00 metric tons along the coast from the 1st sampling events to 4th sampling event. The accumulation rates were high up to about 22 days from the date of incident and no substantial accumulation was noted after 56th day to 94th day at all 7 locations. Locations

at Negombo area appears to be more of an accumulation zone compared to locations at Chillaw. However, before sampling was commenced the Authorities have engaged an extensive beach cleanup operations especially in Negombo area where accumulation rates were very high, and therefore the measured totals were low at those locations. Authorities can engage in final cleaning of the beach with maximum cleaning efforts from August as future depositions appear to be less likely. Cleaning efforts should be concentrated more in Negombo area where accumulated quantities are high.

Key words: Micro-plastics, MV X-Press Pearl Ship, Deposition of Micro Plastic

1. Introduction

Plastic pellets have been reported from beaches across the globe for over several years. Plastic pollutants are generally divided into two categories: mega-plastics and micro-plastics. Mega-plastics (sometimes referred to as macro-plastics) are plastic products larger than 20 mm. according to the U.S. National Oceanic and Atmospheric Administration (NOAA), Micro-plastics are fragments of any type of plastic less than 5 mm (0.20 in) in length.

The Singapore - registered MV X-Press Pearl ship carrying 1,486 containers, including 25 tons of nitric acid, along with other chemicals, cosmetics and oils loaded from the port of Hazira, India, set the journey on 15th May 2021.

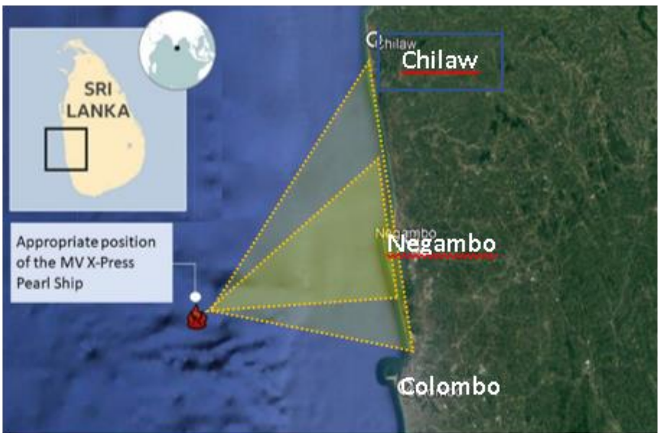


Figure 01: Location of MV X-Press Pearl ship at the fire eruption (the outer tangle indicates approximate dispersion zone of micro plastics and inner tangle indicates the dispersion area carrying high density of micro plastics with the waves indicated based on deposition densities on the beach

On 20th May, a fire erupted on the ship, which was anchored about 9.5 nautical miles (18 km) Northwest of Colombo while waiting to enter the port for emergency dousing of fire. Authorities battled with fire for 13 days but fire was strong enough to ash most of the containers in the ship deck. X-Press Pearl was transporting 78 tons of low - density polyethylene pellets in three containers. An unquantified mass of pellets de - contained due to explosive fire. The incident occurred during a period of strong winds and high waves. Which resulted in onshore movement of the micro plastic pellets and accumulation of massive quantities on the beaches. During the initial period of the incident, there were strong onshore winds (> 10 ms^{-1}) and waves (~2 m). With the onset of the Southwestern monsoons, the Western sea off Sri Lanka was rough, and the micro plastic carrying waves deposited millions of tiny pellets on a large area along the the Western coast. On 22nd May, tropical cyclone Yaas formed in the Northern Bay of Bengal propagated to the North. The strong winds linked with the Cyclone Yaas posed additional challenges on the incident management letting transportation of more micro plastics on country's most popular beaches for tourism and marine ecology. Soon after the incident the authorities started beach cleaning while efforts became challenging as Micro plastic contained waves continued to deposit pellates on the cleaned beaches making the cleaning efforts more and more complicated. While cleaning efforts became challenging the authorities wanted to identify the locations with potentially high deposition rates to deploy its limited resources effectively.

This study was carried out to estimate the total accumulation and the rate of accumulation of micro plastic pellets along the Western coast of Sri Lanka covering the 25.6 km beach section from Negombo to Chilaw, the most affected coast by the MV Express Pearl ship fire incident. As accumulated micro plastic quantities along the shoreline were not uniform due number of factors (wave characteristics, coastal geo-morphology, erosion control measures and bathymetry and etc.) a mathematical interpolation was used to approximate the disposition quantity of micro plastics along the coast. Mathematical interpolations is used to determine or estimate the value of *f(x)*, or a function of x, for certain known values of x. if $x0 < x < xn$ where *x0* and *x1* is known, then the estimated value of *f(x)* is said to be an interpolation. In this study *f(x)* was the derived polynomials and x was the distance from 1st sampling location.

2. Materials and Methodology

The sampling techniques and area selection were based on "Expert Judgement" where errors were minimized as much as possible with detailed inspections around the study locations. Seven sampling locations from Negombo to Chilaw in about 25.6km was selected. Certain locations were not selected as travel restrictions were imposed on the coast from Negombo to Uswetakeiyawa. According to the information this section had the highest deposition of pellets as well as the maximum beach cleaning operations.

Figure 02: A Sampling Location

Sampling was done repeatedly for 3.5 months period (Refer the figure 2). Freshly accumulated micro - plastic pellets in a specific quadrat was collected (Refer the figure 3). The same quadrat was used for all four sampling events. The collected sample were cleaned and separated from sand and debris, and they were washed with distilled water to remove salt depositions on pellet surfaces and dried in air before used to further quantitative analysis. Top loading balance was used to determine the mass of micro plastic pellets and mass per square meter was calculated. Then mathematical interpolation equations were derived for micro plastic pellet accumulation. Type of polynomials across the data point were selected as per the agreement with actual accumulation patterns and they were integrated among specific intervals (length) to calculate the total accumulated amounts along the coast.

In line with the spot density values and the distance between locations from L_1 to other locations, charts with trend lines (length vs density) were plotted and most suitable polynomial patterns were selected by dividing charts into two segments and considering their regression coefficient (r^2). This approach was used since single polynomial pattern could not be fitted to overall accumulation pattern along the sampling locations in a single chart due to shoreline non uniformity characteristics. For the mathematical approximations, interpolated third order exponential and power polynomials were used as most suitable to the non-uniform conditions. The two polynomial segments in each chart was integrated separately as per the bound intervals at the point of break and then each calculated values were added together to calculate the total aggregated amount along the coast. The area under curve is calculated to represent total quantity of micro plastic pellets accumulated along the entire 25.6 km beach section. Relevant integrals are summarized below for four sampling events.

Integral - 28th May

$$\int_0^{25630} y\,dx = \int_0^{14230} 4\times10^{-11}\,x^3 - 6\times10^{-7}\,x^2 + 0.0006x + 13.028\,dx + \int_{14230}^{25630} 68.249e^{-x\times10^{-4}}\,dx$$

Integral-11th June

$$\int_{-0}^{25630} y\,dx = \int_0^{9730} (8\times10^{-10}\,x^3 - 10^{-5}\,x^2 + 0.0389x + 7.7858\,dx + \int_{9730}^{25630} 1623.2e^{-3x\times10^{-4}}\,dx$$

Integral-23rd July

$$\int_0^{25630} y\,dx = \int_0^{9730} 5\times10^{-10\,x\,3} - 10^{-5\,x\,2} + 0.0533x + 1.1635\,dx + \int_{9730}^{25630} 09\times10^{13} \times x^{-3.039}\,dx$$

Integral-14th September

$$\int_0^{25630} y\,dx = \int_0^{9730} 4\times10^{-10}\,x^3 - 7\times10^{-6}\,x^2 + 0.0423x + 1.7841\,dx + \int_{9730}^{25630} 5\times10^{15} \times x^{-3.481}\,dx$$

Figure 03: A sampling quadrat on the beach

Figure 04: Google image of sampling locations from Negombo to Chilaw

Four sampling events was done for 3.5 months period from day of incident , but survey in August could not be done due to imposed travel restrictions and lockdowns for Covid-19 pandemic. The timeline of the sampling is summarized below.

(Incident occurred) (20th May-day 0) ⇨ 1st Sampling Session (28th May-day 8) ⇨ 2nd Sampling Session (11th June-Day 22) ⇨ 3rd Sampling Session (23rd July- day 56) ⇨ 4th Sampling Session (14th September-Day 94)

Figure 05: Timeline of the sampling

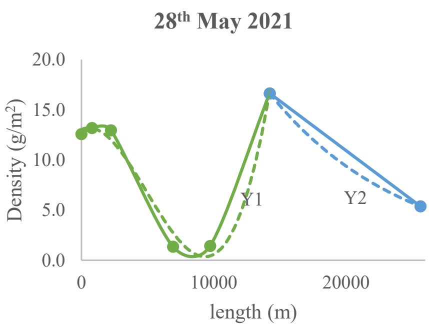
3. Results and Discussion

The density of accumulated micro plastic pellets at each location for the sampling dates are summarized in the table 1. The L_1 and L_2 locations had significantly low pellet density even though the locations were in the high accumulation zone. The reason is the extensive cleanup operation in the L1 and L2 area before and during the initial sampling events. L_3, L_4 and L_5 locations had high pellet accumulation densities. These locations are in the high accumulation zone and also there were no or little clean up works. L_7 location had the lowest pellet density where impact from incident was very low, and beyond L_7, no notable pellets accumulation was found on the coast.

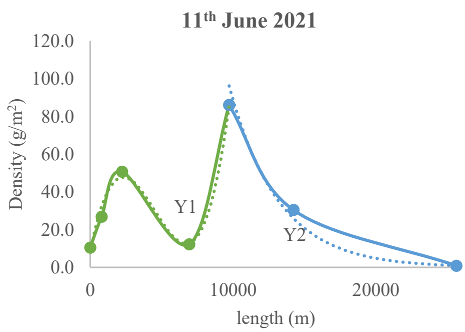
Table 01: Micro plastic pellet density in seven selected locations for four dates of sampling

Pellet Accumulation Zone	Location	Distance to the sampling locations from L_1 (m)	28th May (Day 8)	11th June (Day 22)	23rd July (Day 56)	14th September (Day 94)
			Micro plastic pellets density (g/m^2)			
Nagombo area- High accumulation	L_1	0	12.6	10.6	10.8	8.9
	L_2	805	13.2	26.9	12.6	17.5
	L_3	2230	13.0	50.7	88.0	71.6
	L_4	6930	1.3	12.3	75.8	73.3
	L_5	9730	1.4	86.0	90.9	86.2
Chilaw Area Moderate- low accumulation	L_6	14230	16.6	30.4	14.1	13.7
	L_7	25630	5.4	0.9	4.4	2.8

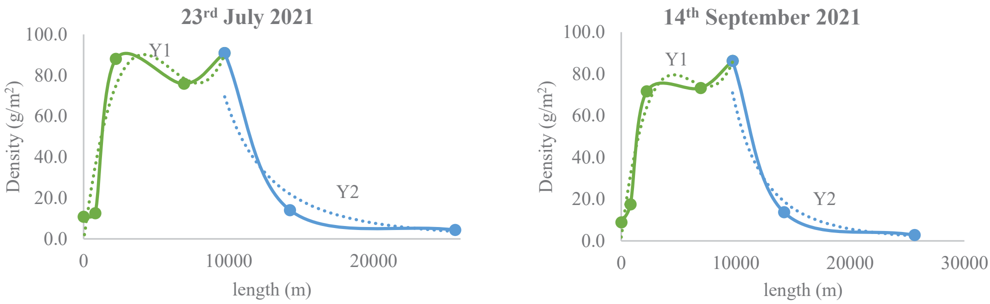
The figure 4 illustrate actual accumulation of the micro plastic pellets in each sampling day, the line graph, and interpolated graph the dotted line. Each polynomial in relevant segments were summarized under each plot. The liner regression coefficient of all derived polynomials were greater than 0.85 that reflects a strong agreement between actual values and the derived curves.



$Y_1 = 4E\text{-}11x^3 - 6E\text{-}07x^2 + 0.0006x + 13.028$
$Y_2 = 68.249e^{-1E\text{-}04x}$



$Y_1 = 8E\text{-}10x^3 - 1E\text{-}05x^2 + 0.0389x + 7.7858$
$Y_2 = 1623.2e^{-3E\text{-}04x}$



$Y_1 = 5E\text{-}10x^3 - 1E\text{-}05x^2 + 0.0533x - 1.1635$ $y = 4E\text{-}10x^3 - 7E\text{-}06x^2 + 0.0423x + 1.7841$

$Y_2 = 9E{+}13x^{-3.039}$ $y = 5E{+}15x^{-3.481}$

Figure 06: Density dispersion pattern charts along the study zones (Actual Vs Modeled)

During the field inspections it was observed that deposition pattern of fresh micro plastics pellets on the coast is synchronized with the pattern of sea waves reaching the beach. There the highest quantity of micro plastic was found on a narrow section of about 1m width along the beach. The waves coming into this narrow band deposits the pellets on the beach while section bellow this band has aggressive wave action and hence pellets do not deposit and get washed back to sea. As the highest density of accumulation was found within the 1m band width, the accumulation zone was considered as 1 m for analytical estimations. The estimated microplate pellets in metric tons are summarized in table 2. According to table 2 the accumulated quantities have increased from 0.19 MT in day 8 to 1.00 MT in day 94 along the 25.6 km beach section.

Table 02: Total mass of micro plastic pellets accumulated in 25.6 km beach section

Date & Day (Day is the number days from the incident)	Total weight of micro plastic pellets along the 25.6 km costal line with 1m band width (g)	Total weight in Metric ton (MT)
28th May (day 8)	191746.8	0.19
11th June (day 22)	929087.7	0.93
23rd July (day 56)	865131.0	0.87
14th September (day 94)	1000329.2	1.00

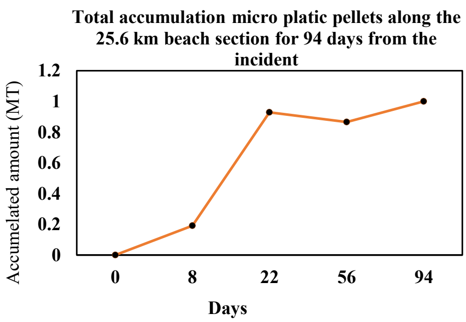


Figure 07: The estimated total accumulation of micro plastic pellets along the beach section of 25.6km from day 8 to day 94

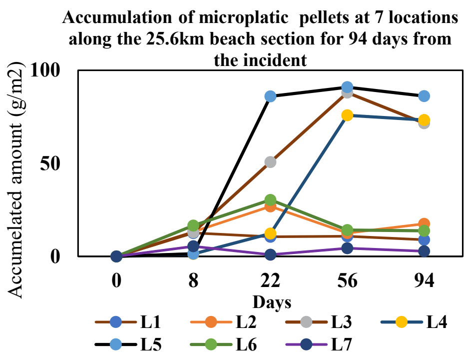


Figure 08: Measured accumulation of micro plastic pellets at 7 locations from day 8 to day 94

The mean accumulation rates were high only within first 22 days and it has almost stabilized after 22nd day with no noticeable net accumulation afterwards. However, extended net accumulations were found in L_3, L_4 and L_5 location up to 56th day, and after 56th day there was no net accumulation in these locations. The location L_6 and L_7 are the furthest sampling points on the coast towards North where total accumulation quantities are low without noticeable rate of accumulation over 94 days. The field observations revealed that no noticeable deposition of micro plastic pellets beyond L_7 location. At L_1, L_2 (Nagombo area) the measured low accumulated quantities were mainly due to extensive beach cleaning operations at these locations. Therefore, if no beach cleaning was done the net accumulations quantities should be high at these locations. The net accumulation of micro plastic pellets at a given location is influenced by the two natural events, i.e. the disposition of pellets on the beach and wash off back to the sea with waves. Accordingly, locations close to Negombo appears be more of a deposition area compared to the locations towards North (Chilaw).

4. Conclusion

The total estimated accumulated micro plastic pellets quantity along the 25.5 Km beach section on the Western Coast from Negombo to Chilaw is 1MT for a period of 94 days starting from 20th May to 14th September 2021. The estimated accumulated quantity is low as part of the accumulated material were removed during beach cleaning operations.

The total accumulation rate was high only in first 22 days, and after around 22nd day there was no Noteworthy net total accumulation, However, at locations in Negombo area the accumulation of micro plastic pellets have been continued for a about 56 days, and after that there were no noticeable net accumulations in all 7 locations for the sampling period.

Authorities can engage in planned cleaning operations from August to clean up beaches with maximum cleaning efforts as new dispositions are less likely. Also, cleaning efforts should be concentrated mostly at Negombo area where estimated and measured accumulated quantities are high compared to Chilaw area.

The National Building Research Organization is continuing the monitoring events in order to observe the long - term deposition characteristics in this zone.

5. References

1. Juliana A. Ivar do Sul, Monica F. Costa, The present and future of microplastic pollution in the marine environment, Environmental Pollution, Volume 185, 2014, Pages 352-364, ISSN 0269-749.
2. Lei Su, Simon M. Sharp, Vincent J. Pettigrove, Nicholas J. Craig, Bingxu Nan, Fangni Du, Huahong Shi, Superimposed microplastic pollution in a coastal metropolis, Water Research, Volume 168, 2020, ISSN 0043-1354.
3. Wenya Luo, Lei Su, Nicholas J. Craig, Fangni Du, Chengxi Wu, Huahong Shi, Comparison of microplastic pollution in different water bodies from urban creeks to coastal waters, Environmental Pollution, Volume 246, 2019, Pages 174-182, ISSN 0269-7491.

INNOVATION GEARED
BUILDING RESILIENCE

Technical Session 2

Technological advancements in building research

Combination of Geophysical Techniques and Core Drilling Models to Evaluate Geology around Underground Excavations; A Case Study at Broadlands Hydropower Tunnel in Sri Lanka

GV Lankathilaka[1], CN Subasinghe[1]

[1]Geologist, National Building Research Organisation, Sri Lanka

Abstract

One of the most key priorities in terms of underground construction is, avoid tunnel failures and design appropriate support systems. Geological, geophysical and geotechnical aspects are the basis of determining the stability and sustainability of tunnels. Many types of features could lead to instabilities in such projects, for instance, underground sinkholes and fracture zones. In this study, Broadlands Hydropower Project has been selected for the gathering of required data. The project includes a 3,420 m length tunnel and one particular part of the selected area had the most subsidence and cracking phenomenon. Ground penetrating radar and electric resistivity are two geophysical techniques which use in the study and are widely accepted in detecting rock property changes in the subsurface. Various levels of data processing are applied to construct a map of the subsurface distribution of physical properties. Core drilling samples along the tunnel trace also used to evaluate the geology of the underground excavations. In BHP, section of the tunnel is running through a karst marble rock filled with saturated clayey silt. The ground above the tunnel line is very weak and much more vulnerable to collapsing and subsiding. Sinkholes are formed by both the failure of solution cavities and the rapid removal of fines from solution cavities in carbonate and metal carbonate rocks. It has been recorded that the most of marble layers are located around the tunnel trace of the area and therefore the tunnel route has been changed during the early stage of the tunnel excavation. Marble outer crops and cavities have been identified as an unpredictable geological layer that is very difficult to identify.

Keywords: hydropower, underground excavation, tunneling, electrical resistivity, ground penetration radar, core drilling

1. Introduction

Underground tunnels have been an important urban infrastructure in ancient Cities, especially in overpopulated areas (Diamond and Kassel, 2018). In Sri Lanka, tunneling history goes back to ancient times. As an example, recently found evidence of a tunnel that belongs to the Kotte kingdom in the vicinity of the Ananda Sasthrayala School. During previous Centuries rapid development of tunneling began with the railway transport system developed after 1842 by Ceylon Government Railway. Since many projects that require excavations are consumed a significate amount of funds, the subsurface investigation is crucial factor for owners and government officials as well as for the planners, engineers, and constructors. When the excavation is made, the strengths of the surrounding ground keep the hole open until the tunnel supports are installed. Because of that, it is very important to get a clear idea about the intended excavation path before the excavation. This is usually done by borehole drilling and logging the samples which are very expensive and time - consuming. Further, underground geology determines the cost and even the behavior of the completed structure. The relationship between geology and cost is so dominant that all practices involved in the planning and designing of the tunnel must give serious consideration to the geology and hydrogeology of the site (Soldo, 2019). Therefore, developing an accurate geophysical model is an essential concept in such projects. The electrical resistivity survey method is a very reliable method that is used in almost every part of the World due to its wide application possibility. Also, a decision such as the general alignment and depth of the tunnel, in or out of an adverse geological feature can be taken based on resistivity data.

Geophysical methods provide indirect measurements about subsurface characters. These indirect measurements are insufficient to draw a definite conclusion and therefore physical samples are required to confirm the conclusion. Because the borehole cost immensely compared to the geophysical survey, the necessity of boreholes can be reduced by applying geophysical methods. Electrical Resistivity (ER) methods, namely resistivity was developed in the early 1900s, is used extensively in the search for ground water sources, to monitor types of groundwater pollution, in engineering surveys to locate sub surface cavities, faults, fissures & etc. In archaeology for mapping out the area extent of remnants of buried formations of ancient buildings, amongst many other applications. It is also used extensively in down-hole logging (Reynolds, 1997). The ER technique of subsurface materials determines the physical composition of the overburden and depth to bedrock and thickness of sand, gravel or metal deposits or aquifer detect fault zones, locate steeply dipping contracts between different earth materials (Lucius, 2006). Using ER data, it is possible to get an idea about the depth to the water table as well as to solid bedrock from the surface and the weak zones in the rock. After the ER survey, boreholes can be drilled at specific locations on the tunnel trace to confirm the findings. This may reduce the number of required boreholes and eventually reduce the total cost of the project.

Since the mid - 1980s, Ground Penetrating Radar surveys (GPR) have become enormously popular, particularly within the engineering and archaeological communities (Neal, 2004). However, radar has been used for geological applications since the 1960s, especially in connection with the development of radio - echo - sounding polar ice sheets. Glaciological applications of radar are now very well developed (Reynolds, 1997). GPR is similar in its principles to seismic reflection profiling and sonar surveying. A short radar pulse in the frequency band 10-1,000 MHz is introduced into the ground (Brooks and Kearey, 1984). GPR has many geological applications, such as; imaging shallow soil and rock structure at high resolution, locating buried channels and mapping the water table.

In the middle stage of the Broadlands Hydropower Project (BHP) subsidence has occurred in the tunnel trace due to unexpected subsidence led by the marble cavity. Further, more than 35 houses that covered nearly one hectare of the Polpitiya area encounter crack development during the crack survey. However, it was noticed that one particular part of the selected area had the most sub sidence and cracking phenomenon. Detailed geological evaluation is a need in the initial stage of a project for safer construction of the tunnel and minimizing the risk of structures located along the tunnel, especially houses in the area. Accordingly, the main objective of this study is to evaluate geology in tunnel trace areas by combining geophysical techniques and core drilling methods.

2. Study area

The study area covers about 1.1 km^2 in Polpitiya at Ambagamuwa Korale Divisional Secretarial Division (DSD) in Nuwara - Eliya District. It is in the Western slopes of the Central Highlands and within the Northing coordinates of 6^{0}97'84.05'' and Easting coordinates of 80^{0}45'26.03'' (Figure 1). The study area belongs to the wet zone this particular area has an average annual rainfall between 3,500 mm to 5,000 mm. Further, the average annual temperature of 27^{0}C. Rainfall is greatly influenced by monsoons and inter monsoons but according to geographical position, this area has more rainfall in South-West monsoon than in North-East monsoon.

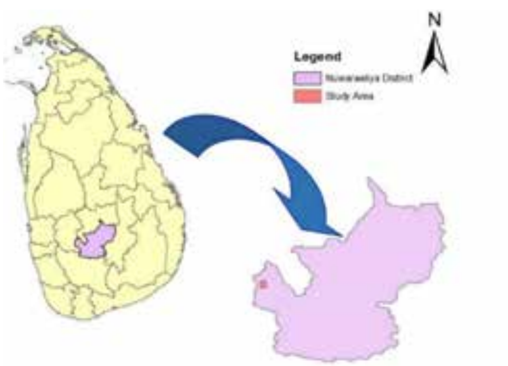


Figure 01: Map showing the study area in the Nuwara Eliya District (Satellite image scale 1:8,000)

3. Methodology

Following figure 2 shows the main steps carried out during this study. Preliminary desk study was carried out before conducting field investigations. General geology of the area, land use pattern, geomorphological conditions and geological structures have been identified during this study. Field observations were made to identify the locations where subsidence occurred and to identify such possible cavity openings and general geology of the area with available rock exposes. The main tunnel route and study area have been identified with GPS coordinates. During the initial field visit, it has observed that the most of houses in this area have been collapsed or were endangered due to the subsidence. Mineralogy, lithology, and special features of each bedrock exposure were noted. Field observations in geology focus on two broad areas such as ongoing geologic processes and outcrops of rocks.

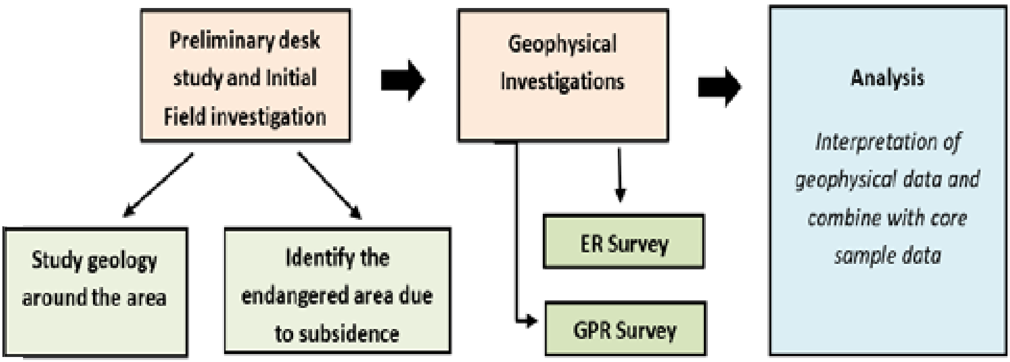


Figure 02: Methodological flow chart for evaluate geology in study area

Many important information on the historical, geological process of the study area has been collected during the field visits. Almost direct examination of the rock samples of the study area, rock composition, grain size, grain shape, rock color, and other structures such as minor folds and minor faults were identified during the direct field observations. Moreover, cracks on the walls and floor of the houses were identified and measured. Both ER data and GPR data were collected for five survey lines in ER and three GPR survey lines. However only two ER survey lines and one GPR survey line has taken for the study (Figure 3). GPR survey was conducted along the road which has 650 m length (Figure 6) with 1.2 m antenna with 10 MHz - 180 Mz, step frequency techniques, that penetrate to a much better depth, up to a 25 - 30 m. Resistivity survey had completed in conjunction with the underground marble and the cracked houses at selected points in the study area using ABEM TERRAMETER LS meter and accessories. For this purpose, twenty-six equidistant electrodes were used in a standard configuration.

GPS survey also carried out by NBRO as feasibility study; early stage of the project. To cover the entire area and due to obstacles, the first GPR survey was done along the road which started from tunnel trace and road (Figure 3). The Figure 6 profile is from the starting point and up to a length of 28 m along the road and due to some difficulties faced in the field this line was discontinued and start, again as a separate file where the 1st line stopped. In this line whole length is having a loose overburden.

4. Results and Discussion

During the field study, it is identified that the most of area has been covered by high-grade metamorphic rocks which can be found all over the study area with very few geological features such as fractures and cracks. Nevertheless, marble or other weak formations have not been identified.

Figure 03: Locations of resistivity sounding, GPR survey lines and core drilling locations of study area (1:1000)

An electrical resistivity survey had to carry out to identify most of the terrain geology by covering adjusting areas of the study area. Topographic features were observed by using five Vertical Electrical Sounding (VES) lines. Figure 3 shows the ER survey profile along the original tunnel route. It clearly shows that the tunnel is running through clay-filled cavities and in fresh rock (right-hand side), on top of the tunnel there are series of highly saturated clay-filled cavities. This can be seriously affected the tunnel construction, itself and also the structures above the tunnel trace with a considerable width (50 m width apart from tunnel trace). This needs to be critically considered during the construction of the tunnel. A proper supporting system during the construction and a properly designed tunnel lining to support the load of upper layers, and must not give a possibility to seep water from upper layers to the tunnel after the completion of the tunnel lining.

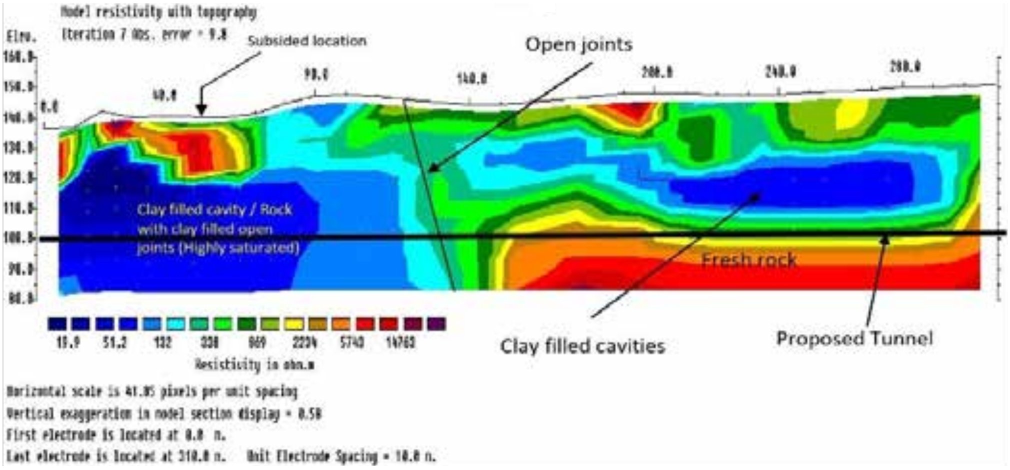


Figure 04: ER Survey Profile along original tunnel route (Line 01)

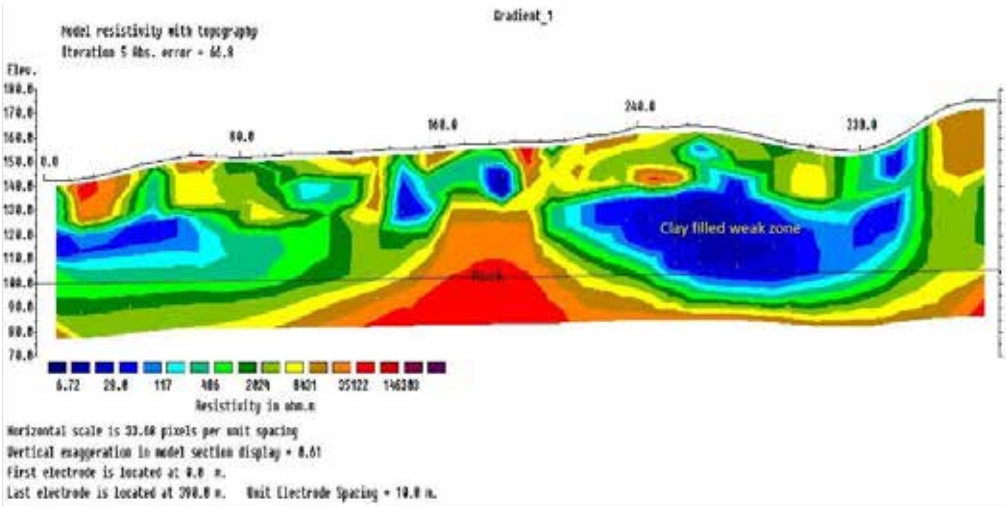


Figure 05: ER Survey Profile along original tunnel route (Line 02)

According to the resistivity model, both profiles show the same type of ground profile visible in the other 20 m parallel line also. Clay - filled cavities, highly weathered rock with a high level of saturation, and shallow groundwater level shows in every section. This long line showing high levels of anomalies up to the depth of 15 m and close to the depth of 29 m in the length from 0 - 75 m, 200 - 250 m, and at 475 m length, there are some anomalies visible. These are probably due to open joints and /or previously collapsing the upper layers.

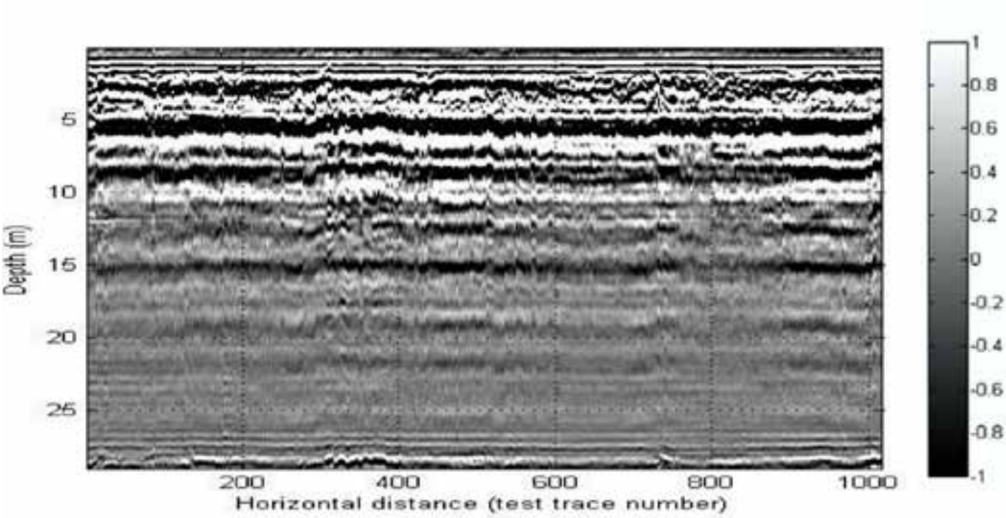


Figure 06: GPR survey line along the road

With regards to the GPR survey that has been done, a proposed tunnel is advancing through a weak ground with open, highly jointed rock blocks which can be identify by the anomalies near 400 m level to both sides. Further, investigation was conducted to cover the existing settlement area (Max 400 m in length) along the tunnel trace the underline geology along the proposed tunnel path, especially from chainage between 80 – 300 m having a series of clay - filled cavities, which can also verify by ER survey results and highly saturated soil with open joints. By comparing both GPR and ER profiles, ground above the tunnel line is very weak and much more vulnerable to collapsing and subsiding. This criterion does not change in new alternative route either. Further, this can be affected by the progress of the tunnel and subsidence of the ground, hence there is a clear relationship between both cracks of the houses and subsidence with respective to the underground geology. This situation was observed 40 m width of the tunnel trace (20 m by each side) according to the GPS survey.

Following figure 7 shows the core drilling profile for the same area with five boreholes. Profiles show hard rocks in the subsurface but no cavities or weak geological formations have been found. This profile covers almost all the area in the alternative tunnel route (Line 02 in figure 5) and yet has not been identified any trace of marble or other layers. However, the core drilling set 2 with zk9 and zk4 boreholes had shown significant marble veins with large cavities very much near to the original tunnel route. Furthermore, every profile from geophysical surveys had found weak formations with water - bearing formations in the subsurface but the data gathered near to alternative tunnel route has not identified any of such formations. Many geological scenarios such as weak formations and limestone cavities are unique formation that has limited to very narrow distance and not wide spread over the area. Which makes it difficult for the geologist to identify its behavior.

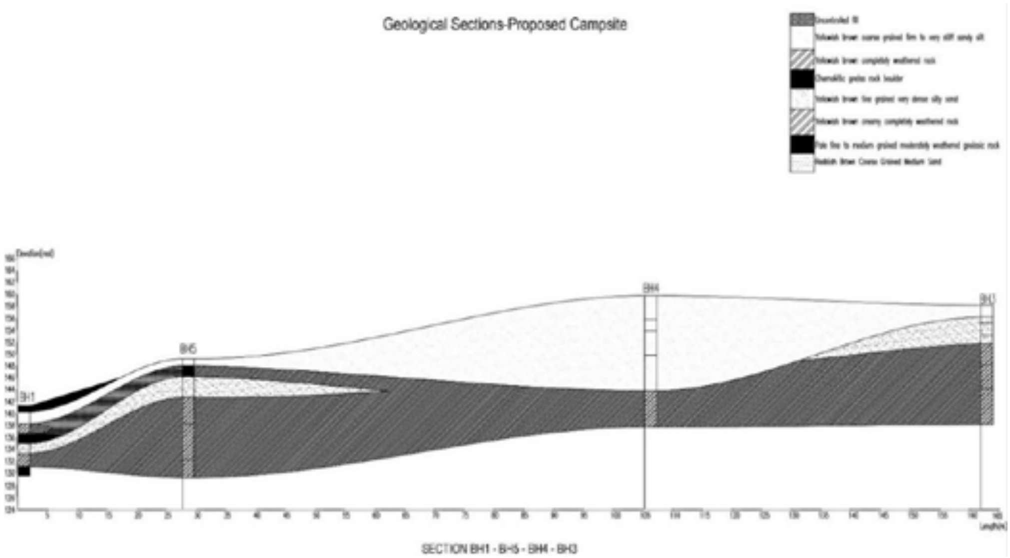


Figure 07: Core drilling profile of first set (BH01, BH02, BH03, BH04, BH05)

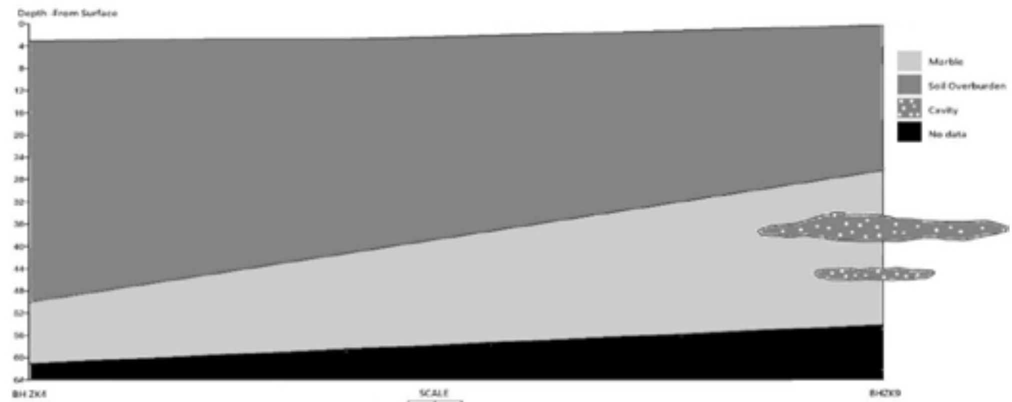


Figure 08: Core drilling profile of second set (zk9 and zk4)

The above figure 8 illustrates the subsurface condition around the original tunnel route and since there are only two boreholes available real extend of cavities had not been recorded. According to the details gathered in the course of the detailed geological survey, it was identified that the underground geology of this particular area consisted of high - grade metamorphic rocks such as Garnet biotite gneisses which are slightly weathered or almost fresh. But it is well noted that marble interconnected caves or thin marble layers within very shallow levels (around 20 - 30 m depth) are present. Firstly, these data were not present in the first core drilling set, namely, BH01, BH02, BH03, BH04, BH05 as in figure 7 do not contain any trace of marble. Secondly, GPS and ER profiles which illustrate the same area show weak formation with cavities (Figure 4 and 5).

Further, the second core drilling set with zk4 and zk9 bore - holes shows marble layers up to 65 m depth. This is a common behavior in marble occurrence which has a very unexpected nature. Moreover, it is widely acknowledged that this kind of phenomenon eventually leads to underground limestone cavities and subsidence of ground. During the GPR road survey, marble outcrops were identified in some places, and most marble layers were expected to be interconnected through very thin fractures or with very few veins. Due to the high rainfall of the study area, most of the marble consisting geological layers are almost dissolved and underground cavities may be widely spread following to as it is an extension.

5. Conclusions and Recommendations

In underground excavations, weak formations like fracture zones, high intense joint planes, faults, clay, marble or any weathered formation increase the risk of failures. In BHP, both geophysical data from GPR and ER found weak formations like clay filled cavities, open joints, cavities in marble around the tunnel axis. The ground above the tunnel axis is vulnerable for collapsing and subsiding. This can be affected to safety of tunnel and damage to houses due to subsiding. Ground water level can be reduced due to the existence of highly fractured garnet biotite gneiss and presence of cavities in the marble.

Borehole data is accurate and precise but it covered a limited area. Geophysical investigations are not much accurate and need to be confirmed by another geophysical method or through the use of physical samples, but for large areas, geophysical data provide a suitable profile than borehole profiles especially there is not many boreholes to cover the entire area.

All the houses at risk should be monitored for crack surveying not only before and during construction but also after completed the tunnel construction.

6. Acknowledgement

Nuwara-Eliya District office of Landslide Research and Risk Management Division of National Building Research Organization, Mr. MIDH Wijewickrama, Senior Geologist are thankfully acknowledged for sharing necessary data and information.

7. References

1. Brooks, M. and Kearey, P. (1984). An introduction to geophysical exploration. Geoscience text. 14, 198-225.
2. Diamond, R. S. and Kassel, B. G. (2018). A history of the urban underground tunnel (4000 B.C.E. - 1900 C.E.). Journal of Transportation Technologies. 8, 11-43.
3. Gamage, K. G. C. P. and Laksiri K. (2018). Latest hydropower development in kelani river basin - Broadlands Hydropower Project. SLEMA Journal. 21(01), 17-21.
4. Lucius J. E., Langer, W. H. and Ellefsen, K. J. (2006). An introduction to using surface geophysics to characterize sand and gravel deposits. U.S. geological survey, Open-File Report 2006-1257.

5. Neal, A. (2004). Ground-penetrating radar and its use in sedimentology: principles, problems and progress. Earth-Science Reviews. 66, 261 - 330.
6. Reynolds, J.M. (1997). An introduction to applied and environmental geophysics, John Wiley, Chichester, New York. 796 pp.
7. Soldo, L., Vendramini, M. and Eusebio, A. (2019). Tunnels design and geological studies. Tunnelling and Underground Space Technology. 84, 82–98.

INNOVATION GEARED
Building Resilience

Design for the Reconstruction of Damaged Buildings Located at Hingurakgoda Divisional Secretariat: A Case Study

AGRP Weerasinghe[1], JPDCM Karunarathne[1], HDJP Samaranayaka[2], TRST Wijewardana[1]

[1]Engineer, National Building Research Organisation, Sri Lanka
[2]Consultant Engineer, National Building Research Organisation, Sri Lanka

Abstract

This study is focused on identification of a rectification methodology for the problem of single storied houses that are in severe structural distress in the Hingurakgoda Divisional Secretariat in the Polonnaruwa District which is within the dry zone of Sri Lanka. The observed structural Distress could have been caused by a combination of facts such as; poor workmanship, poor quality building materials and problematic subsoil conditions. Alluvium soils are found in the flood plain of the river and soils with expansive characteristics were also found elsewhere.

The area is underlain by a Marble layer which is susceptible to forming cavities due to physical weathering. The area was divided into several zones based on the identified potential problematic sub soil conditions listed above and different recommendations were made on a zonal basis.

Cost effective foundation types were proposed based on the column loading and characteristics of the expansive soils found in the area. Cost effective ground modification procedures were identified for the construction of foundations. Guidelines were established on surface drainage also.

Keywords: alluvium, marble, expansive properties, resilient houses

1. Introduction

Houses with moderate to severe distress had been a problem encountered in some parts of Hingurakgoda Divisional Secretariat Division (DSD) and Bubula Grama Niladhari

Division. National Building Research Organisation (NBRO); as a key technical agency in Sri Lanka focusing on geohazards and hazard resilient construction, initiated an investigation based on reported cases in Hingurakgoda following a request made by the District Secretary, Polonnaruwa. Key objectives of the investigation are to identify the causes for distress, assess the condition of damaged houses and propose short - term and long-term measures to mitigate the problematic situation.

NBRO investigated the reported situation and structural stability of damaged houses in Hingurakgoda DSD commencing from 20th August 2019. The investigation covered 223 locations.

As per the initial investigations, NBRO identified 68 houses as with high-risk based on the level of structural distress (Figure 01). Out of that, 10 houses are to be relocated at safer locations considering close proximity to the river and/or adverse sub soil conditions. The balance 58 houses are to be re - constructed at the same location. Since the presence of a thin layer of expansive soil is identified, some ground modification would be required during the reconstruction.

The remaining 164 houses have been categorized as moderate and low risk houses as these houses have lesser structural defects and found to have no significant effects from prevailing soil conditions. Repair and restoration of those houses is possible. These houses are to be monitored after repairing.

Since, the above 58 houses are located in an area where an expansive soil layer is present, swelling during the wet season and shrinking during the dry season is identified as the main reason for structural distress and an appropriate foundation design with necessary guideline on detailed construction process in necessary.

Figure 01: Damaged houses

2. Objective of the Study

The overall objective of this study is to develop strategies that will improve the resilience of low-rise masonry structures in the study area (Figure 02 - Google Map). The following steps were adopted to meet the research objective.

1. A detailed condition assessment for the damaged houses situated within the problematic area was done
2. A geological map was developed for the area (Figure 03)
3. A detailed investigation was conducted to find the problematic soil layers and their thicknesses
4. A hazard zonation map was developed incorporating the gathered information. In these zones where housing construction can be permitted or is prohibited were identified (Figure 03). The 10 houses that are to be relocated are in the prohibited zone. The other 58 houses to be reconstructed at the same locations are in the permitted area. The details are discussed in section 3
5. The ground modifications necessary for the reconstruction of all the houses were identified based on the structural loads and the characteristics of the expansive soils identified. The details are discussed in section 6
6. A model house will be constructed initially following the identified ground modifications. This will provide necessary guidelines for all future constructions

3. Geological Mapping & Hazard Zonation

The total study area is shown in the Figure 02 in a google map.

Figure 02: Study Area marked on Google Maps

Geological zonation map (Figure 03) was developed considering the distribution and depth of existing alluvial soil layer and the weathering condition of underlying marble rock layer. Considering the depth of the alluvium layer, two main zones; critical zone and less critical zone, were identified for consideration of house construction.

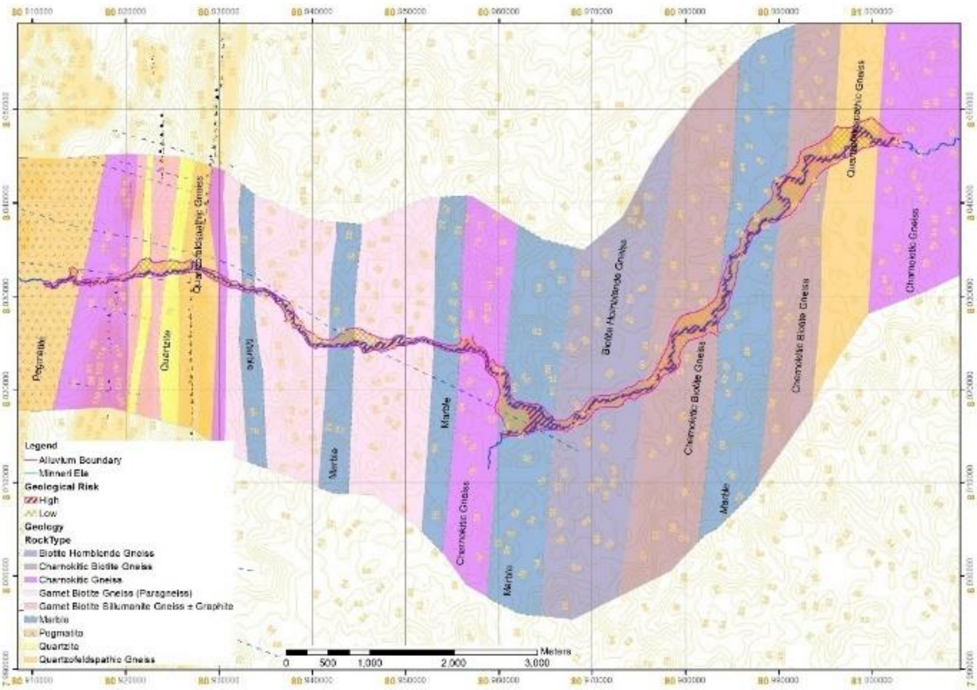


Figure 03: Geological Zonation Map

3.1. Critical (high-red zone)

The areas, which are underlain by alluvial deposits of more than 2 m in thickness and with the houses affected by the suspected fractures and cavities in underlying marble rock layer were considered to be the critical zone. This zone covers the area near to the existing streams. A general recommendation is given not to build new houses within this zone. If the construction is to be allowed in this zone more detailed geotechnical investigation should be conducted by advancing boreholes at specific locations and appropriate foundation design shall be carried out. However, such investigation and suitable foundations could lead to a high cost and were not considered at this stage for construction of low - cost housing.

3.2 Less Critical (low-yellow zone)

Areas, which are underlain by alluvial deposits of less than 2 m in thickness were categorized under this zone. Therefore, new constructions can be done following the relevant guidelines.

4. Remedial Measures

Severely distressed houses should be demolished and reconstructed in accordance with the NBRO guidelines in the low - risk zone. Houses in high -risk zones should be relocated into the low risk zone.

Different guidelines are proposed to be adopted for the new construction in low-risk zones. The objective of the guidelines is to overcome the problems due to expansive soils with different approaches. In the actual implementation one or more of them could be adopted depending on the level of severity. The guidelines are;

- Minimize/prevent ingress of water to the foundation soils which have expansive characteristics
- Remove the expansive soil within the influence zone of the foundations and replace with selected approved material
- Ensure that the foundation load transferred to the ground exceeds the swell pressure

5. Subsurface Condition and Soil Properties

5.1. Subsurface Condition

Subsurface profiles deduced based on the results of the borehole investigation, are summarized in Table 01 & Table 02 Only two boreholes were advanced. (Location 16 & Location 17 in Figure 04)

Table 01: Summary of subsurface profile – Borehole 1

No	Layer	Description	Depth (m)
1	Silty SAND	Top soil layer, generally consists of loose silty SAND layer, SPT N value 6	0.00-0.60
2	Clayey SAND	Underlying the top soil layer, loose to medium dense clayey SAND layer, SPT N value 18 (Alluvial)	0.60-1.25
3	Sandy CLAY	Very stiff, sandy CLAY with some gravels, (Alluvial/ Residual)	1.25-2.00
4	Clayey SAND	Clayey SAND layer. SPT N value 38, and is in a dense state. (Residual)	2.00-2.45
5	Sandy SILT	Sandy SILT layer. SPT N value >50, and is in a very dense state. (Completely weathered rock)	2.45-3.40
6a	Bed rock	Highly to moderately weathered MARBLE layer	3.40-11.00
6b	Bed rock	Highly to slightly weathered, highly fractured BIOTITE GNEISS	11.00-24.10*

*Termination depth

Table 02: Summary of subsurface profile – Borehole 2

No	Layer	Description	Depth (m)
1	Silty SAND	Top fill layer, generally consists of medium dense silty SAND layer, SPT N value 10	0.00-0.20
2	Sandy CLAY	Stiff CLAY layer, (Alluvial)	0.20-1.00
3	Silty SAND/ clayey SAND	Medium dense silty SAND/ clayey SAND layers, SPT N values ranging from 15 to 28 (Residual)	1.00-3.45
4	Silty SAND	Dense to very dense silty SAND layer, SPT N values ranging from 36 to >50 (Completely weathered rock)	3.45-4.90
5a	Bed rock	Highly to moderately weathered MARBLE layer	4.90-8.00
5b	Bed rock	Highly to slightly weathered, highly to slightly fractured BIOTITE GNEISS	8.00-15.50*

*Termination depth

5.2 Soil Properties

To assess the soil characteristics leading to the expansive behaviour a large number of shallow samples (around the foundation depth) were obtained from trial pits. Sampling locations are shown in the Figure 04 and properties of soil collected from seventeen locations are summarized in the Table 03 The soil samples at some locations are found to be expansive according to Chen (2012) and Lucian (2008).

Figure 04: Sampling Locations

Table 03: Summary of measured properties from random selected areas

Properties / Location	Liquid limit (%)	Plasticity index (%)	Clay content (%)	Natural water content (%)	Free swell Index (%)	Swelling pressure (kPa)	Methylene Blue Value (g/100g)
Location 1	30-58	14-38	16-45	5-22	5-15	57	2.8
Location 2	35-58	16-31	23-48	13-20	5-62	36	3.9
Location 3	24-63	7-40	20-46	5-17	5-43	43-58	2.1-2.8
Location 4	26-29	9-13	5-32	8.5-20	5-27		
Location 5	29-32	8-11	23	9-14	5		
Location 6	32-42	13-22	37-42	9-14	10-40	29-58	2.8-3.3
Location 7	28-40	8-22	23-43	7-13	5-10	22-29	2.8-3.8
Location 8	34-42	11-22	29-49	6-16	20-21		
Location 9	32-35	12-15	29-33	4-11	10-21		
Location 10	25-35	8-17	20-32	5-14	5-20		
Location 11	24-29	7-17	10-18	7-12	1-2		
Location 12	32-42	14-26	26-43	10-12	5-21	29	2.1
Location 13	24-53	8-34	33-36	5-17	5-22	36	2.3
Location 14	22-74	5-44	16-53	3-12	5-46	22	1.6
Location 15	26-34	9-17	11-25	5-9	14-32	22	1.8
Location 16	25-56	7-29	21-42	10-28	11-71	15-58	
Location 17	35-36	10-11	27-42	13-16	6-17		

6. Foundation Recommendation

Layout of the proposed model house is shown in the Figure 05 Different resilient features and foundation options that can be adopted are presented here. The most appropriate features should be adopted considering the severity of the problem at the location and the economic viability.

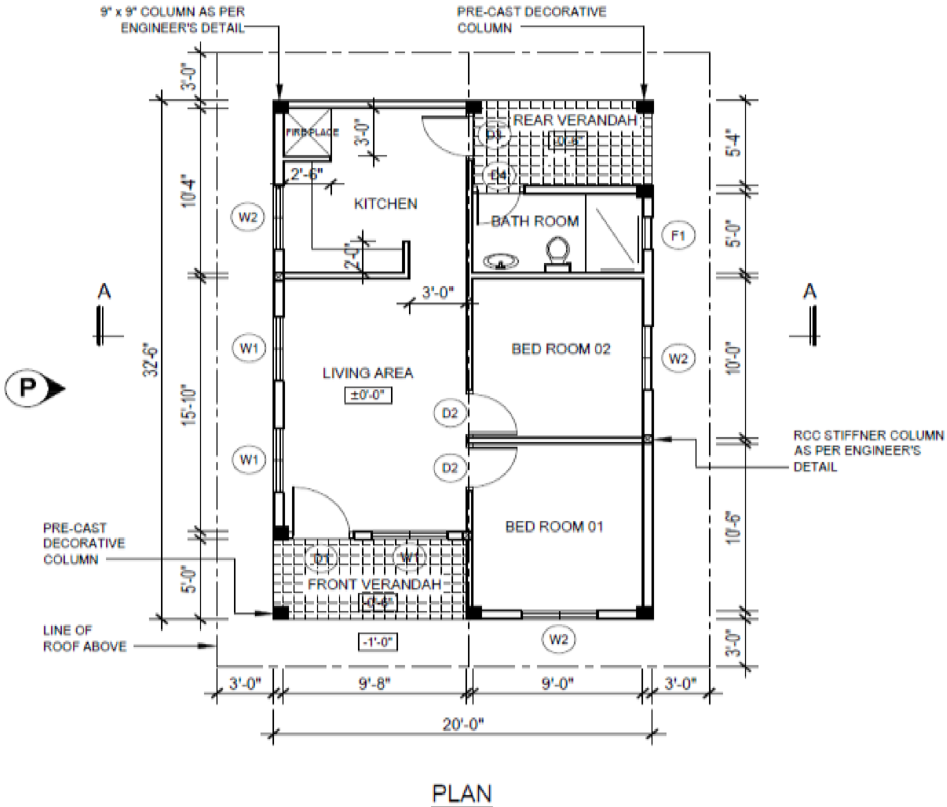


Figure 05: Layout of the House

6.1. Foundation Type 1 - Strip Footing

Reinforced concrete strip foundation consists of a RC strip at the base with a rubble wall and RC plinth beam at DPC level. Ground improvement is done by replacing expansive layer down to a 6 ft (600 mm) depth and replacing with well compacted granular soil. Gauge 1,000 polythene layer is introduced to separate the fill soil. In addition, 4 RC columns supported on pad footing were provided at the four corners to increase the rigidity of the structure without having any interior columns. Sub soil in the overall house foot print and an area of width 5 ft (1500 mm) along the periphery are also to be excavated to 1 ft (300 mm) below existing ground level and replaced with well compacted granular soil. Foundation details proposed are given in Figure 06 Figure 07 illustrates the different construction stages of the completed of the model house using Foundation Type 1.

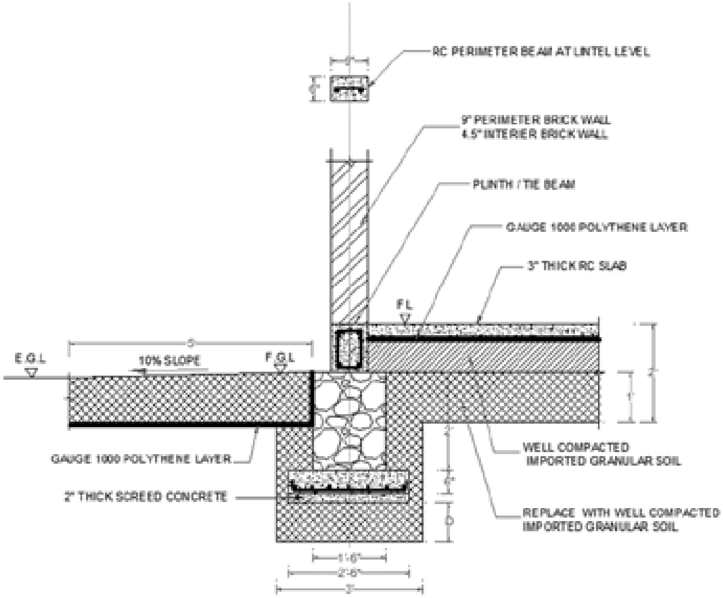


Figure 06: Foundation Type 1

Figure 07: Images of construction of the resilient model house as per the Foundation Type 1

6.2. Foundation Type 2 - Pad Footing

Individual reinforced concrete pad footing with RC stub column and plinth beam is considered. The decision for replacement of soil under the foundation is taken after considering the bearing pressure imposed by the structural loading.

Column footings layout proposed with foundation type 2 is shown in Figure 08

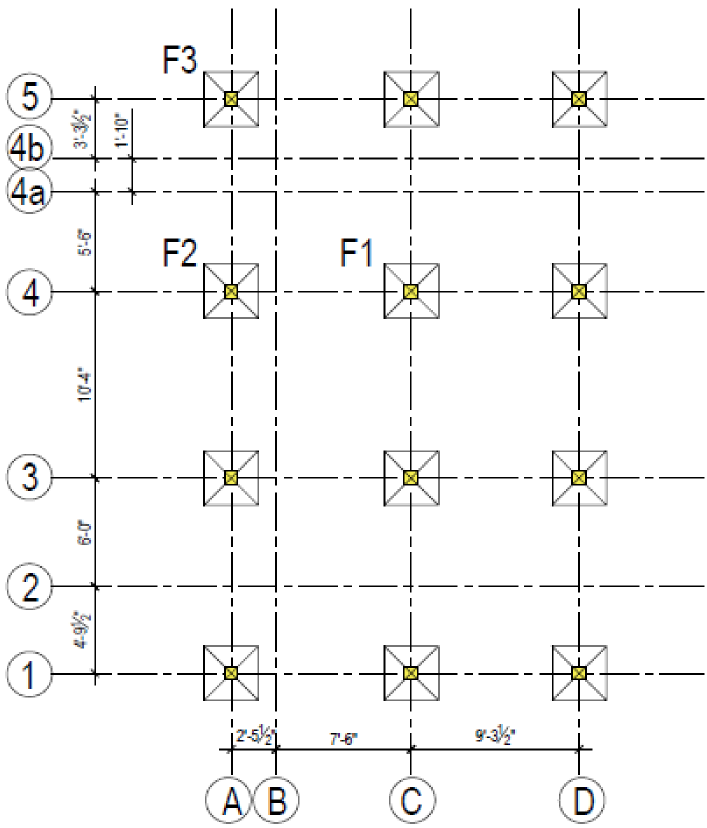


Figure 08: Footing Layout

6.2.1. Pad footing (inner) F1(0.76 m × 0.76 m)

Expected maximum service load to the individual pad footing = 84 kN

Let's consider individual pad footing having dimension 0.76 m × 0.76 m

Therefore, required bearing pressure $=84/(0.76 \times 0.76)$

$=145\ kN/m^2$

Bearing Pressure > Maximum Swell Pressure

6.2.2. Pad footings(edge) F2 (0.6 m × 0.6 m)

Expected maximum service load to the individual pad footing = 20 kN

Let's consider individual pad footing having dimension 0.6 m × 0.6 m

Therefore, required bearing pressure =20/(0.6 ×0.6)

=56 kN/m^2

Bearing Pressure ≈ Maximum Swell Pressure

Accordingly, the effect from the swelling pressure on the footings F1 & F2 will be overcome due to the higher pressure imposed by the structure and the foundation. Hence the foundation can be constructed without any soil replacement and the foundation detail presented in Figure 09 can be recommended.

However, corner footing F3 is subjected to a lesser bearing pressure than the maximum swell pressure. Therefore, ground improvement (soil replacement) needs to be carried out to avoid an uplift movement of the foundation due to the change of moisture content underneath the footing. Hence the foundation detail presented in Figure 10 (Type 3) is recommended.

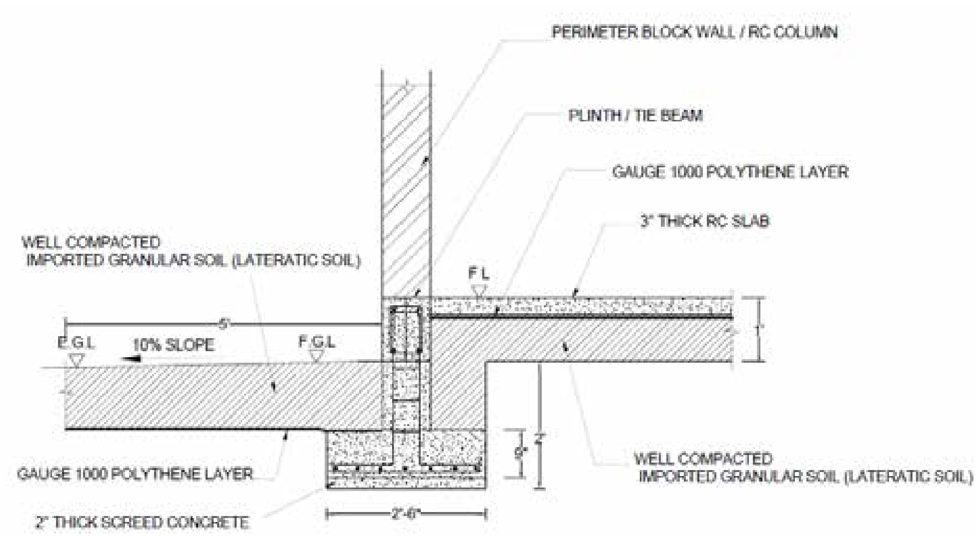


Figure 09: Foundation Type 2

6.3. Foundation Type 3 – Pad Footing with Ground Improvement

Individual reinforced concrete pad footing with RC stub column and plinth beam. Ground Improvement will be carried out under the footing area and the floor area.

Following assumptions were considered for the ground improvement,

- Thickness of the expansive clay layer is equal to 2 m
- Maximum swell pressure up to the 1.5 m is equal to 58 kPa
- Maximum swell pressure from 1.5 m to 2 m is less than 30 kPa

Construct the foundation with ground improvement - soil replacement (Ref Figure 09). Proposed foundation type is isolated pad footings.

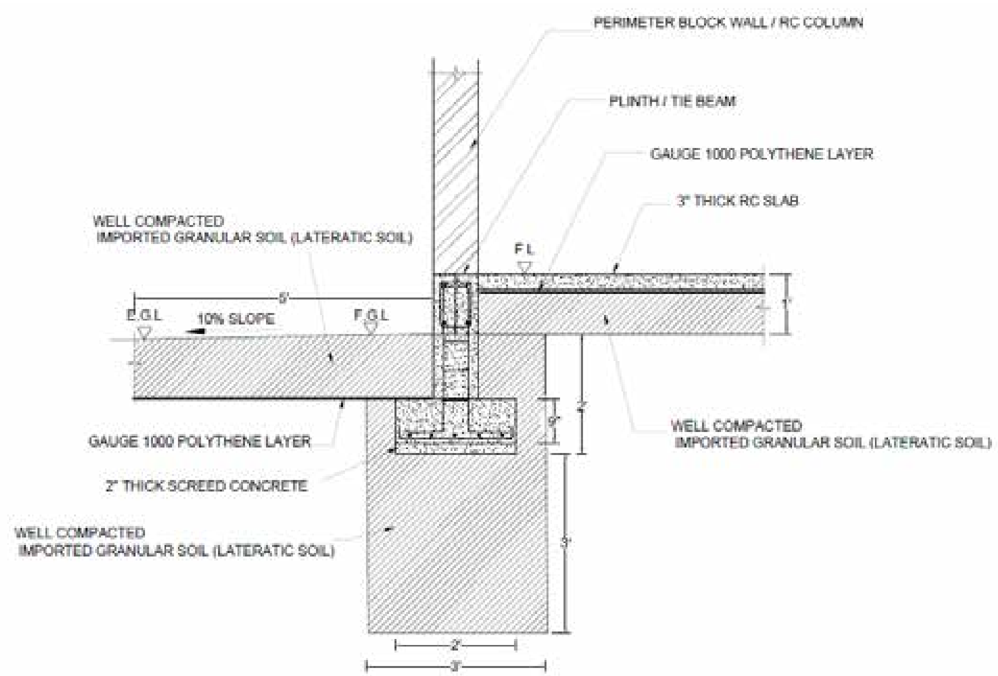


Figure 10: Foundation Type3

6.4. Construction of Plinth Beams when Pad Foundations are Used

Reinforced Concrete plinth beam 0.225 x 0.3 m is built to support the walls of the structure and connect the individual footings. Partial replacement of existing soils and stiffened foundation can reduce differential settlements to a greater extend increasing the rigidity of the foundation (Figure 11).

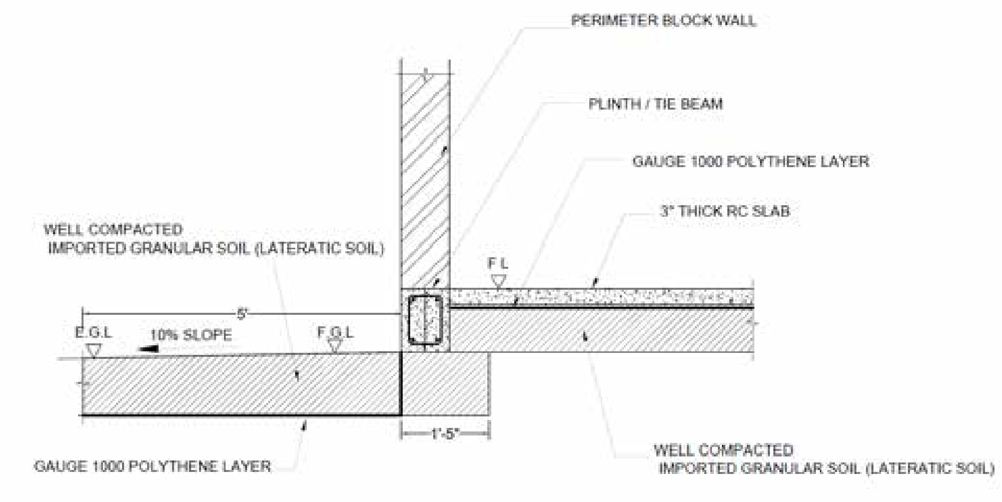


Figure 11: Plinth Beam (Under walls)

Imported granular non - expansive soil fill should be separated with existing problematic soils by using gauge 1000 polythene layer in between to hinder moisture movement. Therefore, it is proposed to construct the new houses with Pad footings and plinth beams with the combination of foundation type 2 and type 3.

6.5. Proposed Ground Improvement Area

Ground improvement area under the footings with the foundation type 3 is given in the Figure 12 and ground improvement along the perimeter is given in the Figure 13

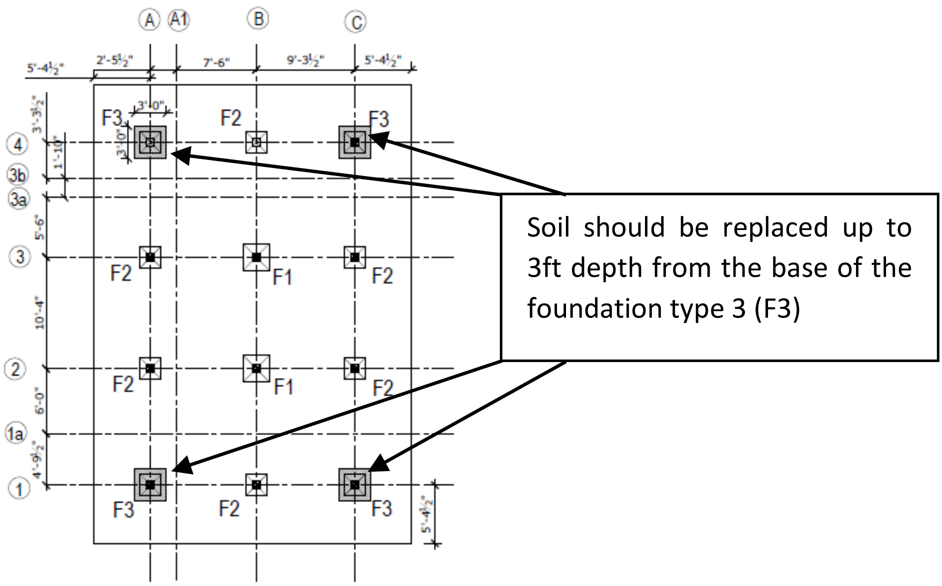


Figure 12: Ground Improvement Area Under Footings

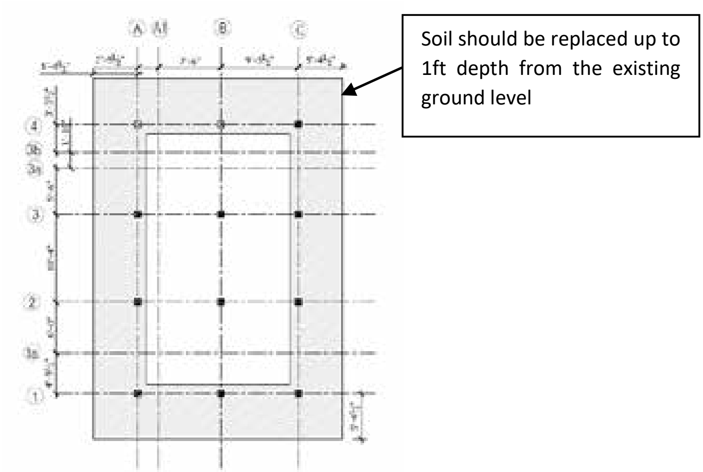


Figure 13: Ground Improvement Along the Perimeter

7. Discussion and the outcome

7.1. Cost Analysis and selection of the optimum option

Table 04: Cost Analysis and selection of the optimum option

Proposed foundation Type	Cost for the proposed Substructure
Foundation Type 1 - Strip Footing	Rs. 882,771.27
Foundation Type 2 - Pad Footing	Rs. 419,573.31
Foundation Type 2 & Type 3 - Pad Footing with Ground Improvement	Rs. 441,887.73

Foundation Type 1 has resulted in additional cost for the foundation construction when compared to an ordinary construction. Hence, foundation options with alternative column /plinth beam arrangement were considered for reducing the cost, construction time and environment pollution. Combination of foundation type 2 & type 3 was selected based on the technical judgements as well as by considering cost components.

7.2. Way forward

This study presents experimental method of construction of single storied resilient houses on the thin layer of expansive soil while providing a proper guidance for the occupants regarding the nature of the expansive soil. However, further research works have to be carried out in order to identify the cost - effective construction methods and different kinds of materials that can be used to strengthen the existing houses by considering the availability and cost effectiveness.

8. References

1. Chen, F.H., 2012. Foundations on expansive soils (Vol. 12). Elsevier.
2. Lucian, C., 2008. Geotechnical aspects of buildings on expansive soils in Kibaha, Tanzania (Doctoral dissertation, KTH).

Analysis of the Waste Sludge Produced from the Offshore Sand Processing Plants in Sri Lanka

SADAS Suraweera[1], PSS Fernando[1], SSK Muthurathne[2], SP Guluwita[3]

[1]Scientist, National Building Research Organisation, Sri Lanka
[2]Director, National Building Research Organisation, Sri Lanka
[3]Senior Lecturer, Department of Materials Science and Engineering, University of Moratuwa, Sri Lanka

Abstract

With the increasing demand for sand in the construction sector, off shore sand has been produced daily by Redeco and Asset sand washing plants in Muthurajawela, Sri Lanka. During the processing of off shore sand, off shore sand sludge (OSS) is produced as a by product that accumulates approximately 150 cubes per month. Currently, the sludge is used either in land filling or has been dumped haphazardly at different locations and thus giving rise to different environmental issues. Hence this research study is mainly focused on mediating this emerging environmental problem by utilizing this sludge in the construction industry. The suitability of OSS in terms of chemical and physical properties was investigated for cement - based products in order to use OSS as a building material. Since chemical and physical properties directly affect the properties of the post - produced value-added product, sludge samples from the sand dump were characterized using the XRF method. Sieve Analysis, Loss on Ignition, Water Absorption, Water-soluble chloride, Sulfate content, Total sulfur content and Organic Impurities tests also were carried out to determine the compliance of sludge as a building material. XRF test results revealed that the predominant compounds of OSS are SiO_2 and CaO. By analysing the results obtained for particle size distribution, shell content and the chloride and sulfate contents it was concluded this waste sludge can be used as an alternative filler material in the development of cement - based mortar type material. More specifically this study aimed to develop and use this OSS for the production of a cement-based tile adhesive material.

Keywords: Offshore sand sludge; Particle size distribution; Shell Content; chemical composition

1. Introduction

Waste generation is a continually growing problem at Global, Regional, and Local levels resulting in increased environmental concern. But this problem has also provided a window of opportunity to find solutions through waste management and recycling waste into sustainable construction materials which will ultimately help out in the area of environmental pollution and economic development of the Country.

The use of fine aggregate is essential to the construction industry and its demand has escalated due to the rapid growth and development of the construction sector. River sand, which is the widely used fine aggregate in Sri Lanka, is being over - extracted to cater to the current industry demand and this has progressed into adverse environmental impacts (Piyadasa, 2011). Therefore, as a solution, off - shore sand was introduced in the mid - nineteen nineties by the Sri Lanka Land Development Corporation (SLLDC) as an alternative to river sand while promoting the protection of the environment and sustainability of the construction industry.

A considerable amount of off - shore sand sludge (OSS) is generated each year from off - shore sand production plants in Sri Lanka. Currently, this OSS is not utilized as a value-added product and is generally used for land filling or dump haphazardly. Land fill disposal of the OSS is not economically viable because it drains the capacity of the land. The use of OSS as a raw material to produce building product can be regarded as an economically and environmentally feasible method to manage OSS.

Past researches have proven the effective use of various kinds of waste sludge (water treatment sludge, municipal sewerage sludge & etc.) as building materials (Johnson, Napiah, & Kamaruddin, 2014) Therefore, the feasibility of similar use of this sludge would be an economical solution and it would also help in completing a proper waste management process which in return minimize negative environmental impacts. This aims to identify the effective use of OSS for construction products/ materials as a solution to waste management. Physical and chemical properties are major concerns of OSS and determine the correct path to the suitability of OSS in developing a value-added building product.

1.1. Offshore Sand Sludge

The processing of off - shore sand produces sludge as a by - product that accumulates daily. It is estimated that around 150 cubes of waste sludge are generated per month. Currently, this OSS is not utilized as a value-added product and is used for land filling or discharging to the water streams. Off - shore sand dredged from the sea may consist of a variety of contaminants, including microorganisms, inorganic and organic contaminants. These contaminants may be existing as suspended soil particles or dissolved constituents. Direct discharge of sludge to water bodies affects the water quality of downstream and aquatic biota and it is not acceptable by Environment protection agency (EPA) recommendations. This discharging of waste sludge into water bodies without concerning the environment leads to the accumulative rise of aluminium and other metal concentrations in water, aquatic organisms and human bodies.

Another problem is due to the accumulation of OSS piles, it consumes extra land spaces and the costs of machinery in transporting and dumping is a burden to the SLLDC. Therefore further improvements are needed to alter the reusing techniques and disposing of methods for OSS which produce as a by - product of the off - shore sand washing process and it is essential to maintain environmental sustainability to reduce the pollution.

OSS is the relatively concentrated solid into which the residual solids fraction and other organic and inorganic impurities arising from off - shore sand washing are concentrated in the course of purification. OSS is derived from the processes of washing and sieving at sea sand plants. The chemical composition and physical properties of the OSS depend typically on the characteristics of the raw off - shore sand, that are types of organic and inorganic compounds dissolved in the off - shore sand, amount of dissolved salts in off - shore sand, amount of clay, fine silt and fine dust in the off - shore sand, the amount of shell content and the amount of coal residues in off - shore sand. Because the off - shore sand which is used as a fine aggregate in the construction industry must be free of these impurities. For that off-shore sand is undergone the process of washing and sieving in which OSS is produced. Eventually the OSS consist of a large amount of impurities.

2. Methodology and Characterization

2.1. Sample collection

OSS samples were collected from different places in sand dumping places in Muthurajawela using the sampling spear as given in the (BS EN 932-1, 1996)standard. This particular standard for sampling specifically introduces methods for the preparation of aggregate samples from places such as preparation and processing plant dumps and stocks. A sample is a specifically selected portion of interest for testing which represents properties of bulk. This particular standard provides methods that are also suitable for the preparation of samples to be tested separately and methods for the reduction of the sample.

2.2. Chemical Composition

XRF (X-Ray Fluoresce) test was done to find out the chemical composition of the OSS sample. The analysis was done by the method of X-Ray Fluoresce which was carried out at the Sri Lanka Institute of Nanotechnology (SLINTEC). HORIBA Scientific XGT- 5200 X-ray Analytical Microscope was used to detect elements. It has the ability to detect elements from 11Na to 92U. The elemental percentages generated by the instrument are given as a percentage of the total detected elements and not the actual elemental composition. Therefore, the total detected elements percentage values are added up to 100%. Six different spots per sample were analysed. Parameters were set as follows. XGT Diameter: 100 µm, X-ray tube voltage: 50 kV, Processing time: P4, Live time: 200 s.

2.3. Particle Size distribution

Particle Size Distribution is a measurement of the size distribution of individual particles in an OSS sample. The main features of particle size distribution are the dispersion of OSS into discrete units by mechanical means and the separation of particles according to size limits using sieving. Sieve analysis was carried out to check the particle size distribution of OSS and it was done according to the (ASTM C144, 1999) standard.

2.4. Water absorption & Particle Density

Water absorption and particle density values give an idea about the strength of aggregate and these tests were carried out in accordance with (BS EN 1097-6, 2000) standard. The testing procedure mentioned as the "Pyknometer method for aggregate particles between 0.063 mm and 4 mm" was used for the testing. Particle density was calculated from the ratio of mass to volume in terms of apparent particle density (ρ_a), Particle density on an oven-dried basis (ρ_{rd}), and Particle density on the saturated and surface - dried basis (ρ_{ssd}). Water absorption value was calculated after immersing the sludge sample for 24 hours in water and as a percentage of the dry mass of the sample.

2.5. Loss on ignition

The loss on ignition (LOI) test is a specific test used in the analysis of volatile substances in minerals. It involves heating the sample to elevated temperatures or igniting the sample allowing volatile components to eliminate until a constant mass is obtained on the sample. This test was carried out in accordance with (BS EN 1744-1, 1998) standard.

2.6. Organic impurity test

The organic impurities test is the widely used test method for the determination of organic materials in fine aggregates samples. In this case, samples are mixed in a, color less glass bottle with 3% sodium hydroxide solution. This test is specifically used for the determination of the presence of organic compounds in the OSS sand. The test serves as a quality or purity test of a particular sample before the utilization of certain applications. The major role of this test method is to find out harmful amounts of organic impurities which may be present in samples to be tested by observing if there are any color changes or showing off a darker color than the standard color occurs due to organic impurities in the sample according to the test method (ASTM C40/C40M-20, 2020).

2.7. Shell content

Shell content of OSS is determined in accordance with (SLS 1397, 2010). The OSS test portion is decomposed by hydrochloric acid and shells are dissolved in the acidic environment and gases are released. The percentage of the mass loss is expressed as shell content in the fine aggregate.

2.8. Acid Soluble sulfate

Acid soluble sulfate content of OSS in accordance with (BS EN 1744 - 1, 1998), Clause 12. The OSS test portion is decomposed by hydraulic acid under reducing conditions. The sulfides are converted into hydrogen sulfide, which is carried over by a gaseous stream into an ammonium solution of zinc sulfate. The precipitated zinc sulfides are determined by iodometry.

2.9. Total sulfur

The total sulfur content of the OSS, determined in accordance with (BS EN 1744 - 1, 1998), clause 11. The OSS test portion is treated with hydrogen peroxide and hydrochloric acid to convert any sulfur compound present to sulfates. Any sulfates are precipitated as Barium Sulfate ($BaSO_4$) and weighted. The sulfur content is expressed as a percentage by the mass of the aggregate.

2.10. Water - soluble chloride

The water - soluble chloride ion content is limited by specifications in order to provide corrosion protection of the reinforcing elements in concrete structures. The method of analysis of the extract is based on that of Volhard titration. Where access of silver nitrate solution is added to the chloride solution and the unreached portion is back titrated with a standardized solution of thiocyanate, using ammonium iron (III) sulfate as an indicator. This water - soluble chloride salts content is determined in accordance with (BS EN 1744-1, 1998), clause 7.

3. Test Results & Discussion

The Sri Lankan Government has encouraged to use of off shore sand as a reasonable substitute for river sand in the construction sector. The Country has the advantage of the accessible large oceanic area to extract sea sand for offshore sand production for the local construction. Although, there are several disadvantages of using off shore sand as fine aggregates, caused by the composition, chemical properties, shell content, and the distribution of particle size depending on sand sedimentation budget and ocean eco system of a sand harvesting area. Thus the properties of OSS also can be varied upon these factors and analysis of the OSS for its chemical and physical properties is important before using this waste sludge for any particular end uses in the construction sector.

Chemical composition was determined using the XRF techniques and the results are shown in Table 01. Predominant compounds present in the sample were SiO_2 and CaO, where the average mass percentage of SiO_2 is 49.51% and CaO is 30.73%. It is a very high amount compared to the average mass percentage of other oxides in the sample. As higher the content of silica, it gained chemical inertness, considerable hardness, and resistance to different weathering conditions (Alshahwany, 2011). But the existence of a considerable percentage of CaO can affect the properties of the final product which is going to be produced using this sludge. As XRF analysis gives the elemental composition but not the type of the compound (E.g. CaO or $CaCO_3$) in the sample, there is a high probability for the presence of CaCO3 which also may indicate under the amount of 30.73%. Because, offshore sand hugely consists of materials containing $CaCO_3$ such as shells, coral, algal and other ocean debris.

Table 01: XRF test results (Oxide form mass percentages)

Compound	Mass %						
	Spot 1	Spot 2	Spot 3	Spot 4	Spot 5	Spot 6	Average
SiO_2	53.757	38.113	46.473	36.396	49.09	73.201	49.51
CaO	30.215	44.084	39.466	41..670	24.447	15.459	30.73
Al_2O	8.606	6.769	6.914	9.135	10.568	4.489	7.75
Fe_2O_3	2.794	3.352	3.887	5.538	8.016	2.507	4.35
TiO_2	1.121	2.92	1.912	1.385	3.179	1.612	2.02
MgO	1.978	2.638	-	3.435	0.634	1.169	1.97
SO_3	0.762	1.162	0.899	1.271	1.121	0.656	0.98
K_2O	0.579	0.458	0.358	1.029	2.617	0.776	0.97
SrO	0.12	0.184	-	-	0.171	0.086	0.14
ZrO_2	0.017	0.24	-	-	-	-	0.13
Yb_2O_3	-		-	0.082	-	-	0.08
WO_3	-	-	0.081	-	-	-	0.08
MnO_2	-	0.047	0.011	0.042	0.117	0.045	0.05
Cr_2O_3	0.052	0.028	-	0.017	-	-	0.03
ZnO_2	-	-	-	-	0.04	-	0.04

Sieve analysis to study the particle size distribution of OSS was carried out as per (ASTM C144, 1999) for two samples which were collected from two different OSS stockpiles at Muthurajawela. Table 02 shows the obtained sieve analysis test results, and cumulative passing percentage vs. sieve size curves are also illustrated in Figure 01. The graph indicates that both graphs are almost the same in their shapes and there is no any particle size variation of the OSS samples. Also, it can be clearly concluded that the particle size of the majority (~90%) OSS is within the 0.075 mm and 0.6 mm size range. The aggregate particle size is a very important parameter affecting the strength of construction materials. According to sieve analysis test results expressed that OSS has low grain size, hence the sand sludge has a suitable grain size to be used as a fine aggregate to be used in construction purposes, such as aggregate for mortar type products and tile adhesive products (Jenni, Holzer, Zurbriggen & Herwegh, 2005). Since void content of the mortar is also affected by the sand grading, binder consumption increases and whereby conveys to mortar retraction (Haddad, Neves, de Oliveira, dos Santos & de Carvalho Junior, 2020; Winnefeld et al., 2012) Nowadays, researchers study the different kinds of filler materials in cement - based composites, more specifically there are some studies about using dolomite, calcite or limestone fillers which consist $CaCO_3$ and $MgCO_3$ to cover the fine particle range (Hayilu & Sahu, 2013; Petit & Wirquin, 2013; Winnefeld et al., 2012) of the mortar. Therefore, if OSS use as a filler material for the tile adhesive production, it covers the 0.5 mm - 0.1 mm range (natural sand fillers) and less than 0.1 mm range (carbonate fillers). Furthermore, It is may add more bonding properties because of the higher percentage of CaO consist in OSS (Ozkahraman & Işık, 2005).

Table 02: Sieve analysis test results accordance with ASTM C144-99

		Sample 01	Sample 02
Original Mass (g)		405.5	395.29
Dry mass (g)		374.93	368.77

Sieve Size(mm)		4.75	2.36	1.18	0.6	0.3	0.15	0.075	pan
Cumulative percentage passing (%)	Sample 01	100.00	100.00	99.87	99.12	91.36	35.76	11.14	7.84
	Sample 02	100.00	100.00	99.87	99.03	91.00	28.09	10.12	6.93

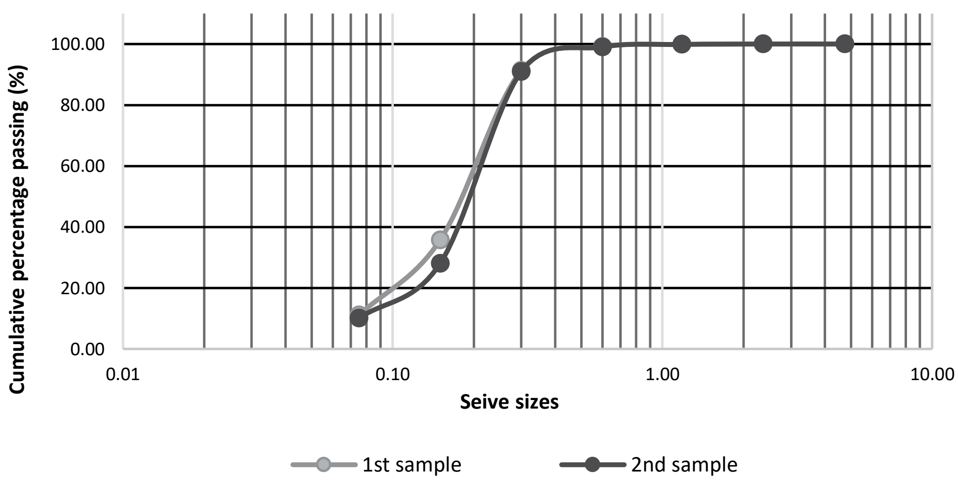


Figure 01: Sieve analysis of OSS

To get an idea about the quality and the water holding capacity of OSS, water absorption and density were tested and the test results are tabulated in Table 03. According to the requirements stated in (BS EN 1097-6, 2000), the water absorption value for fine aggregates should be less than 5%. Therefore compared with the obtained test results, water absorption and density values show a promising attribute towards using this OSS as a filler aggregate. Also aggregates having more water absorption are more porous in nature and are generally considered unsuitable unless they are found to be acceptable based on strength, impact and hardness tests (Zhang & Zong, 2014).

As the organic matter contaminated with aggregates may have a retarding effect on the strength of cementitious materials, a qualitative test for organic impurities was done according to (ASTM C40/C40M - 20, 2020) and it shows darker color than the standard color due to organic impurities in OSS (Figure 02). This test produces no numerical values; thus determination of the precision and bias is not possible. Therefore LOI test was carried out to analysis the driven - off water content, organic matter, inorganic carbon, and minerogenic substances in the OSS quantitatively. The maximum amount obtained for LOI is 8.9 (m/m%) as shown in Table 04. The presence of organic matters in sand usually accounts for a detrimental effect on the bonding between the aggregate and cement paste, while dimensional instability of such material could be another possibility because organic matters are not stable (Olonade, Ajibola, & Okeke, 2018).

Table 03: Water absorption and density results accordance with BS EN 1097-6:2000

Property	Sample 01	Sample 02
Water absorption (%) as of oven-dry mass	0.43	0.45
Specific gravity on an oven-dried basis	2.66	2.64
Specific gravity on saturated surface dried basis	2.67	2.66

Figure 02: Supernent color comparison with standard color plate according to ASTM C40

Shell content of the OSS is carried out as per (SLS 1397, 2010) which is for concrete and mortar, and the maximum shell content obtained for the tested OSS samples was 11.6 (w/w%) and it falls below the maximum limit of the requirement (15 w/w%) mentioned in the above standard. Generally, off shore sand contains shells within the range of 3 - 5 (w/w%). But maximum shell content of OSS is well higher than that. Shells in the OSS can not be seen directly with the naked eye. Therefore, it should be in the form of crushed shells or fine shells in the sea sand. A high amount of CaO (As per XRF results) presence in the OSS is probably due to the fine shell particles. Also, it might be another acid-soluble component that contributes to a high value of shell content test.

Chlorides present in aggregates may dissolve in the mixing water and promote corrosion of any embedded material and may also cause efflorescence. Also, the presence of sulfate may lead to the expansion of mortar and therefore there is a maximum limit for each of these chemical properties as per (BS EN 13139, 2002) which is for Aggregates for Mortar. The test results obtained for Chloride content, acid - soluble sulfate, and total sulfur for OSS have been tabulated under Table 04. All the chemical properties showed lesser values than the values permitted in the standard. Specified maximum limits of the chloride content for the plain mortar, acid-soluble sulfate and total sulfur are 0.01 (w/w%, as a Cl^-), 0.2 (w/w%, as SO_3^{-2}), and 1 (w/w%, as S). Therefore no unfavorable contribution to use OSS as a filler material for tile adhesive mortar material, as they will not be dominant in forming of efflorescence on exposed surfaces of mortar, corrosion of the metal embedded in mortar, rising an expansive disruption and producing of unsightly deposits on exposed surface (BS EN 13139, 2002) s.

Table 04: Chemical properties of OSS

Chemical Properties	Test Method	Sample 01	Sample 02
Organic impurities/LOI (m/m%)	EN 1744-1	0.99	8.9
Acid soluble sulftate (as SO_3^{-2}, w/w%)	EN 1744-1	0.004	0.003
Total sulfur content (as S, w/w%)	EN 1744-1	<0.01	0.002
Water-soluble Chloride (as Cl-, w/w%)	EN 1744-1	0.003	0.003
Shell Content (w/w%)	SLS 1397:2010	2.02	11.6

4. Conclusions

OSS is a sandy material, which has a high amount of organic matter and fine shell partials. But it has less amounts of chloride, acid-soluble sulfate, and sulfur contents that would be beneficial in the production of cement - based mortar materials. SiO_2 and CaO are predominant elemental oxides present in OSS and the majority of the particles are in between the 0.6 mm to 0.075 mm range. While most of the sludge properties show it can be used as a filler material for the production of cement - based composites and more specifically as a filler material for cement-based tile adhesive production, a noticeable presence of organic matters discourages the above judgment, because the presence of organic matters can have detrimental effects on cementitious products. Therefore researchers intend to use the OSS as the filler material of cement-based tile adhesive by replacing natural sand and carbonate fillers while meditating the problem of the presence of organic matters.

5. Acknowledgments

The authors wish to express their gratitude to the laboratory staff at the Building Materials Research and Testing Division and the Environmental Studies and Services Division of NBRO for the support given during this project.

6. References

1. Alshahwany, R. B. A. (2011). Effect of partial replacement of sand with limestone filler on some properties of normal concrete. Al-Rafidain Engineering Journal (AREJ), 19(3), 37-48.
2. ASTM C40 / C40M-20. (2020). Standard Test Method for Organic Impurities in Fine Aggregates for Concrete: ASTM International, West Conshohocken, PA.
3. ASTM C144. (1999). Standard Specification for Aggregate for Masonry Mortar: ASTM International, West Conshohocken, PA.
4. BS EN 932-1. (1996). Test for general properties of aggregates - Part 1: Methods for sampling: British Standards Institution.
5. BS EN 1097-6. (2000). Tests for mechanical and physical properties of aggregates. Determination of particle density and water absorption.: British Standards Institution.
6. BS EN 1744-1. (1998). Tests for chemical properties of aggregates - Chemical analysis: British Standards Institution.
7. BS EN 13139. (2002). Aggregates for mortar: British Standards Institution.
8. Haddad, L. D. d. O., Neves, R. R., de Oliveira, P. V., dos Santos, W. J., & de Carvalho Junior, A. N. (2020). Influence of particle shape and size distribution on coating mortar properties. Journal of Materials Research and Technology, 9(4), 9299-9314.
9. Hayilu, F. A., & Sahu, O. (2013). Tile adhesive production by Inorganic materials. International Journal of Innovation and Applied Studies, 3(3), 866-870.
10. Jenni, A., Holzer, L., Zurbriggen, R., & Herwegh, M. (2005). Influence of polymers on microstructure and adhesive strength of cementitious tile adhesive mortars. Cement and concrete research, 35(1), 35-50.
11. Johnson, O. A., Napiah, M., & Kamaruddin, I. (2014). Potential uses of waste sludge in construction industry: a review. Research Journal of Applied Sciences, Engineering and Technology, 8(4), 565-570.
12. Olonade, K. A., Ajibola, I. K., & Okeke, C. L. (2018). Performance evaluation of concrete made with sands from selected locations in Osun State, Nigeria. Case studies in construction materials, 8, 160-171.
13. Ozkahraman, H., & I ık, E. (2005). The effect of chemical and mineralogical composition of aggregates on tensile adhesion strength of tiles. Construction and Building Materials, 19(4), 251-255.
14. Petit, J.-Y., & Wirquin, E. (2013). Evaluation of various cellulose ethers performance in ceramic tile adhesive mortars. International journal of adhesion and adhesives, 40, 202-209.

15. Piyadasa, R. U. (2011). River sand mining and associated environmental problems in Sri Lanka. Sediment Problems and Sediment Management in Asian River Basins; IAHS: Hyderabad, India.
16. SLS 1397. (2010). Fine Aggregate for concrete and mortar: Sri Lanka Standards Institute.
17. Winnefeld, F., Kaufmann, J., Hack, E., Harzer, S., Wetzel, A., & Zurbriggen, R. (2012). Moisture induced length changes of tile adhesive mortars and their impact on adhesion strength. Construction and Building Materials, 30, 426-438.
18. Zhang, S., & Zong, L. (2014). Evaluation of relationship between water absorption and durability of concrete materials. Advances in Materials Science and Engineering, 2014.

INNOVATION GEAREC
Building Resilience

The contribution of the National Building Research Organization on Deeghawapi Stupa Restoration in Sri Lanka

LAEL Perera[1], DR Ratnasinghe[2], SADAS Suraweera[2], SSK Muthurathne[3]

[1]Manager Technical, National Building Research Organization, Sri Lanka
[2]Scientist, National Building Research Organization, Sri Lanka
[3]Director, Building Material Research and Testing Division, National Building Research Organization, Sri Lanka

Abstract

Sri Lanka is a Country that has a prolonged history of over 2500 years and it has a remarkable place for its sacred sites. On the other hand, these sites have been able to provide a massive tourist attraction to the Country. Therefore, from time immemorial, many Governments have made various efforts to preserve these heritage sites. The National Building Research Organisation (NBRO) has played a crucial role in these conservations. This paper focuses on an on going project conducted under the supervision of the National Building Research Organisation. The conservation work of the "Deeghawapiya" stupa, has been resumed with the assistance of the Sri Lankan Armed Forces. Further, the brick selection process, sampling, testing and the systematic approach carried out by the Department of Archaeology are executed under the supervision of the NBRO. Prior to obtaining soil for brick production (Brick Earth), the samples are tested and the soil suitable for the production process is selected according to the percentage of clay and sand. In the selected brick earth, Clay content should be between 20% - 30%(W/W) and sand content should be less than 50%(W/W). Clay bricks manufactured using the selected brick earth should satisfy the minimum requirements for Type 2 Grade II clay bricks as per the SLS 39 : 1978. Further clay brick production improvements will be made under NBRO supervision as per the suggestions, which will lead to efficient and high - quality clay bricks production. Additionally, to be used for this project, NBRO is currently inspecting the reusability of the remaining bricks gathered from the "Sandahiru Saya" stupa construction project. In this regard, the Building Materials Testing Division (BMRTD) recently conducted testing of five samples from different brick manufacturers. The dimensions, water absorption, and the compressive strength of those brick were tested to investigate the quality of the bricks. Besides the quantitative analyses performed by the BMRTD, the contribution of NBRO

to the manufacturing process of bricks complying with the required quality standards is reported in this paper. Further, the NBRO has contributed to similar projects in the past and intends to continue to do so.

Keywords: Deeghawapiya stupa, Conservation, Water absorption, Compressive strength.

1. Introduction

Sri Lanka has a long tradition of in habiting four major World religions. As the religion of the Sinhala majority, Buddhism has shaped the history and culture of the island more than any other Religion. This is the reason that the shrines of the island have attracted tourists and travellers for over several hundred years. Therefore, many Governments in Sri Lanka have made various efforts to preserve these heritage sites. Over the past few decades, many conservation projects have been carried out. The Building Material and Testing Division of the National Building Research Organisation has been providing their technical assistance on these conservation projects over the years. In the year 2021, NBRO was involved in the conservation project of restoring "Deeghawapiya" Stupa with the support of the Sri Lankan Army and the Department of Archaeology. In this manuscript, the involvement of NBRO in this ongoing project was discussed.

2. Methodology

At the beginning of May 2021, the conservation project of Deeghawapiya Stupa was restarted with the assistance of the Sri Lankan Army, NBRO and the Department of Archaeology. For this restorations work, NBRO was engaged in providing expert advice for the site inspection and the manufacturing process of the clay brick production. Currently, highly skilled materials engineers, scientists and technical staff are involved in the project.

Due to the continuous failure of produced clay brick for this project, the Ministry of Defence and Department of Archaeology decided to take expert advice to overcome the problem. In June 2021, the engineers and scientists participated in a site inspection to observe the project plan and the current practices of the clay brick manufacturing process. The Sri Lanka Army, who are involved in the project at the site, was very supportive of the investigation. After the initial inspection, suggestions were given to improve the clay brick manufacturing process and all the responsible parties were agreed to implement the modification under the supervision of NBRO. Furthermore, quality control activities carried by the Department of Archaeology were also formalized. Sampling method and water absorption test for durability assessment with proper laboratory practices were introduced to maintain the quality clay brick production. Since July 2021, two staff members including one technical officer have visited the project to inspect the brick manufacturing process daily (Ministry of Defence, 2021). At the site, the clay bricks were tested for water absorption and compressive strength in accordance with the test standard of SLS 39 : 1978 (SLS : 39, 1978). Also, the clay content of the soil used to manufacture bricks was restricted in the range of 20% - 30% (W/W) and the sand content was kept less than 50% (W/W). All the data were provided to the Building Material Research and Testing Division (BMRTD) at the NBRO for scientific analysis. All these data were carefully analyzed by the experts and further improvements were recommended.

Suggested improvements were introduced in the following stages in the clay brick manufacturing process. Those improvements and the testing of fire brick were shown in Figure 1.

- The selection process of clay is required for brick production
- Preparation of the selected clay for manufacturing bricks
- Making green bricks using prepared clay
- Drying of green bricks
- Prepare kilns for firing green bricks
- Corrections on the method of inspection

Figure 01: Brick making process and the test for compressive strength

With regard to the restoration of Deeghawapi Stupa, the NBRO was engaged in testing the construction materials gathered from the construction project of the "Sandahiru Saya" stupa. Here randomly selected few remaining brick samples were delivered to the laboratory of the Building Materials Research and Testing Division by the Department of Archaeology, Sri Lanka. These samples were grouped into 4 different groups considering the manufactured locations.

Figure 02: Received samples from four different locations (a) Alayapaththu, (b) Bogoda, (c) Galkadawala, and (d) Mahiyanganaya

The conditions of the delivered samples were also recorded. Then the samples were oven - dried at 110 °C. After 24 hours, the weights of the bricks were recorded and the samples were immersed in the water bath. The test for compressive strength was conducted after 72 hours. The samples were not tested for the maximum bearing load due to its' extreme compressibility. Therefore, the compressive load was recorded at the initial crack observed. The testing was conducted according to the test standard of SLS 39: 1978 (SLS : 39, 1978) All the statistical analyses were conducted by using the software Origin Pro Lab (Origin 8.5, 2010).

3. Results and Observations

3.1. Results of the testings of manufactured bricks at "Deeghawapi" stupa conservation project

In the conservation program, the brick manufacturing process is analyzed continuously to standardize the manufacturing process. For this purpose, a large amount of data is gathered from different manufacturing lots for the analysis. Considering the analysis of the testing and the data shown in Figure 3 for compressive strength, it was noted that the bricks produced at Lot No: 68 in Zone 04 have significant strength compared to the others. The lowest strength observed is 2.6 MPa for Lot No: 69 in Zone 04. According to the standard for burnt clay bricks (SLS : 39, 1978), the type 2 grade II bricks should have the least strength value of 2.8 MPa. It was observed that all the strength data collected from several trials are having strength greater than the required strength.

Water absorption of all the samples was recorded as less than 15%. The highest water absorption observed is 14.4% in Zone 03 Lot 57. Compared to the other test data, Zone 03 Lot 72 recorded significantly lower water absorption which is 11.1%. According to the SLS 39 standard (SLS : 39, 1978), the maximum absorptivity of 28% is specified for the type 2 grade II clay bricks. Therefore, all the bricks tested satisfy the water absorption requirement specified in SLS 39 (see Figure 3).

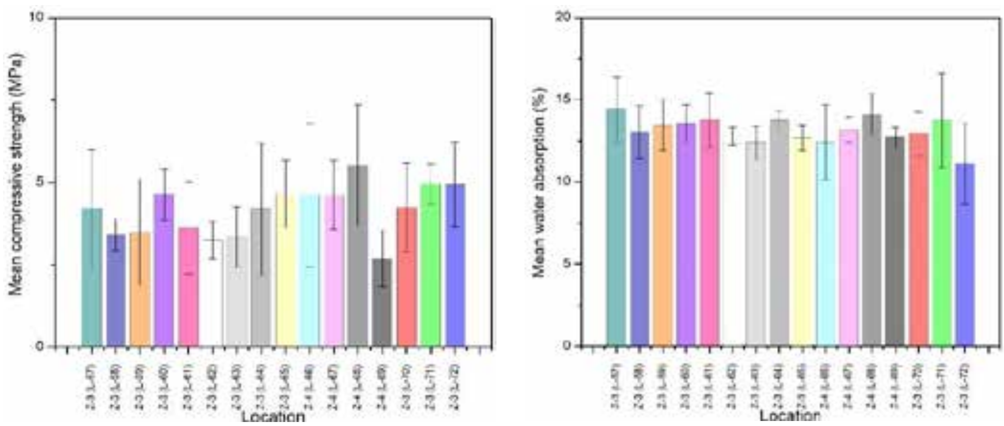


Figure 03: Compressive strength and water absorption data gathered from different zones and lots

3.2. Results of tests on reusability of remaining bricks collected from the "Sandahiru Saya" stupa construction project

In this regard, clay bricks were delivered from four different locations to analyze the reusability. Several properties such as dimensions, mass, water absorption and compressive strengths of the bricks were measured and analyzed. According to the test data, the quality of the clay bricks was analysed considering the manufacturing locations. Figure 4 (a) represents the mean dimension variation for different manufacturing locations. The total volume of brick was calculated to analyze the dimensional variation.

According to the above analysis, it can be observed that the "Alayapaththu" and "Mahiyanganaya" manufacturing locations do produce larger clay bricks than other manufacturers. Conversely, the "Bogoda" manufacturing location produces the bricks with the lowest in size and the variation of the dimensions of the bricks is also the lowest compared to the other manufacturers. The "Galkadawala" location produces bricks with considerable volume, but the variation of the dimensions is too high compared to the other manufacturers.

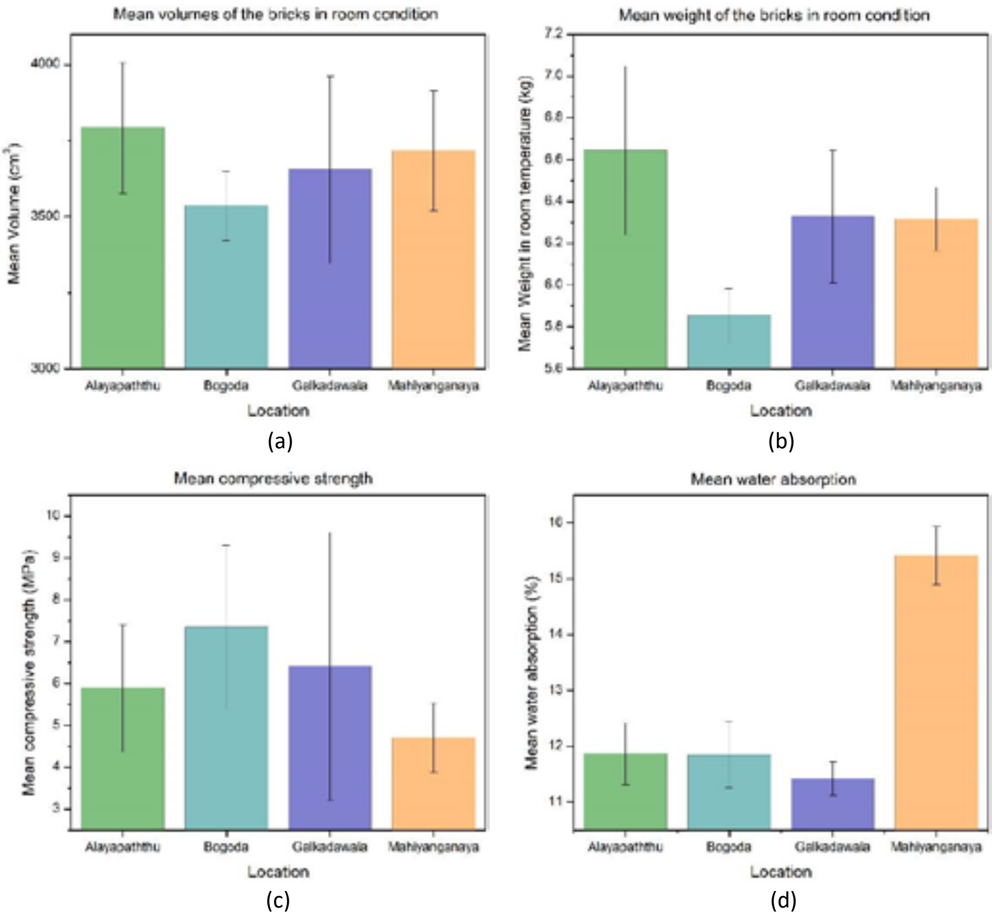


Figure 04: Variation of the parameters in room condition for different manufacturing locations (a) Mean Volume, (b) Mean weight, (c) Mean compressive strength, and (d) Mean water absorption

The variation of the weight of the clay bricks is shown in Figure 4 (b). According to Figure 4 (b) "Alayapaththu" manufacturing location shows the highest weight and the largest variation. Conversely, the "Bogoda" manufacturers produce the clay bricks with the lowest weight. This variation is significant compared to the other brick manufacturers. Also, the weight of the bricks of "Galkadawala" and "Mahiyanganaya" manufacturers show significant similarity.

The water absorption of the clay bricks was tested after oven drying the test samples. According to the test results shown in Figure 4 (d), the clay bricks from Mahiyanganaya showed the highest water absorption. It shows an extreme water-absorbing property and due to this significant value, selecting bricks from this location for the conservation project is not preferred. Conversely, the water absorption of the clay bricks from

"Alayapaththu" and "Bogoda" manufacturers showed significant similarity, On the other hand, bricks from the Galkadawala showed the lowest water absorption property. All the bricks do have similar variations from the mean water absorption value.

Finally, the compressive strengths of clay bricks from different manufacturers were measured and analyzed. Figure 4 (c) represents the mean compressive strengths variation for different manufacturers. Considering the test results shown in Figure 4 (c), the bricks delivered from the Bogoda manufacturing location showed the highest compressive strength compared to the other manufacturers. The bricks delivered from "Alayapaththu" and "Galkadawala" locations also showed significant compressive strength except the bricks delivered from "Mahiyanganaya". However, the bricks from the "Galkadawala" location recorded the highest variance compared to the test results of other clay bricks.

According to the tests carried out, it was noted that the shapes of the bricks were irregular and it was observed that those deformations vary in different scales. The maximum failure load was not observed due to the extreme compressibility. Therefore, the load at the stage of initial cracking was considered in calculating the compressive strength of bricks (see Figure 5).

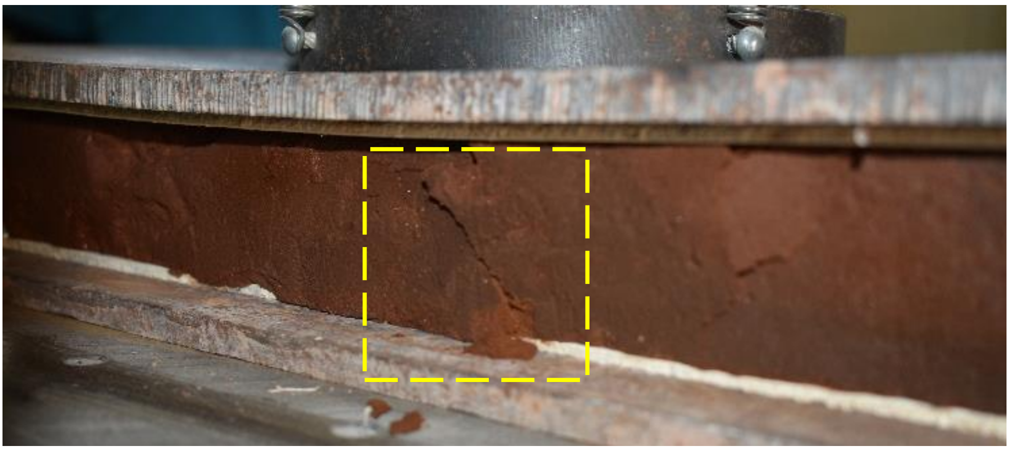


Figure 05: Initial crack observation of the test for compressive strength

4. Discussion and Conclusion

This paper discussed the involvement of NBRO in the current practices of a conservation project. Additionally, scientific analyses of the data correspond to the properties of bricks used for the restoration work of the "Deeghawapiya Stupa" were also discussed. The scientific staff of the National Building Research Organization investigated the brick production process and contributed their expert knowledge to enhance the quality of the manufacturing process Meanwhile, the scientists at the laboratory had been engaged in conducting laboratory testings on the remaining bricks gathered from the "Sandahiru Saya" construction project. The aim was to identify the highest quality bricks received from four different locations and check the reusability of the bricks for the "Deeghawapiya" stupa restoration project. In this regard, clay bricks collected from the four different locations were tested for dimensions, water absorption, and the compressive strength. Considering all the results and observations collected from the test, it can be concluded that the bricks delivered from the Bogoda location showed significant reusability.

5. References

1. Ministry of Defence. (2021). Deegawapiya Stupa restoration operates in a rapid phase. Retrieved 14 October, 2021, from http://deegawapiya.lk/News/view_news/19
2. Origin 8.5. (2010) (Version 85E): OriginLab Corporation, Northampton, MA, USA. Retrieved from https://www.originlab.com/index.aspx?go=Products/Origin
3. SLS : 39. (1978). Common burnt clay building bricks: Sri Lanka Standards Institute.

Cost-Effective and Speedy Mass scale House Construction Using Precast ALC Panels for Resettling Conflict-Affected Families

K Raakulan[1], ST Wijewardena[1], PHCS Rathnasiri[2]

[1]Engineer, National Building Research Organisation, Sri Lanka
[2]Senior Scientist, National Building Research Organisation, Sri Lanka

Abstract

Conventional construction technologies are often incapable of controlling major project requirements such as cost, duration, and quality in mass construction. Further, mass scale house construction with the use of conventional technologies is being criticized for associated damage to natural environment due to over extraction of natural raw materials such as sand, soil and timber. Thus, use of alternative building materials and construction technologies are being investigated in the context of sustainable materials, speedy construction and cost effectiveness. This paper emphasizes the house construction method with the usage of Autoclaved light - weight Concrete (ALC) panels under the project of constructing pre - cast concrete panel houses for conflict affected families in Northern and Eastern Provinces of Sri Lanka under the technical consultancy of National Building Research Organisation (NBRO). Construction of houses with the use of ALC panels is recognized as a cost effective, speedy construction method using a durable product. ALC panel is a construction material pre - fabricated in standard sizes. In brief, ALC is a porous light weight concrete consists of a cellular structure obtained by in situ gas - producing chemical reactions. Hence, the density of the concrete is low when compared with normal concrete. It is used as a replacement for the masonry wall for speedy construction as it can be transported and mounted easily with minimum manpower. This paper highlights the proposed technology and practical issues in the implementation of such a new technology in Sri Lankan context.

Keywords: mass scale houses construction, alternative building materials, ALC

1. Introduction

Government of Sri Lanka initiated a project to provide permanent houses for conflict affected families in Northern and Eastern Provinces. Further, it had been decided to construct pre-fab cost-effective concrete panel houses as per a proposal submitted by a consortium of partner agencies. The proposed housing technology is based on Autoclaved Light-weight Concrete (ALC) panels, which had been proposed to import from China. Speedy construction ability and low cost associated with construction comparative to the conventional housing methods in Sri Lanka are the main advantages. Total house requirement has been estimated as 40,000 houses, where decision has been made to construct 28,000 houses in the Northern and Eastern Provinces of Sri Lanka as the Phase 1 of the project. National Building Research Organisation was appointed as the Technical Consultant to the project as per the cabinet decision.

This paper discusses the proposed housing technology and practical issues associated with the implementation process of such a new technology in Sri Lankan context.

2. Proposed Housing Technology

The house construction technology with the use of ALC panels has been introduced to Sri Lanka by a consortium of partner agencies for the mass scale housing construction to resettle conflict - affected families. The main goal of this project is to construct houses within a shorter period while adhering to the required standards and within a low budget comparative to conventional houses. The State Ministry of Rural Housing and Construction & Building Materials Industries promotion is implementing this housing project with the technical support of NBRO.

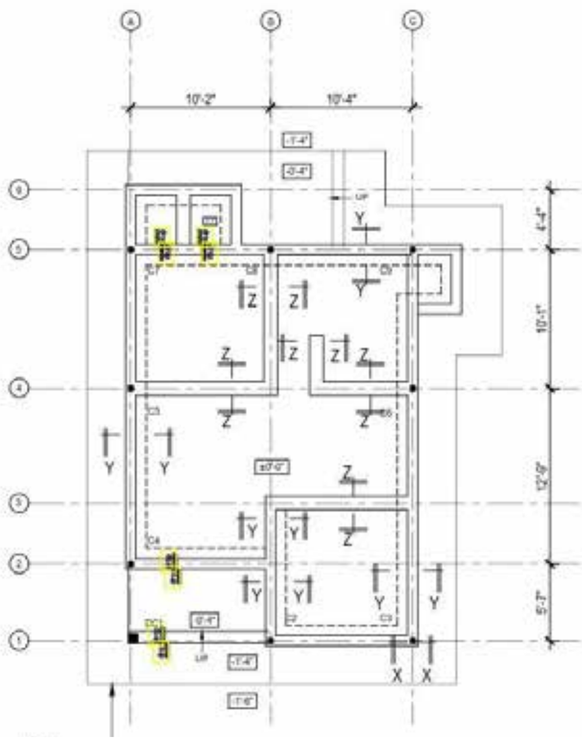


Figure 01: Plan view of the proposed house

The proposed house design consists of 650 sq.ft of floor area, having two bed rooms, a kitchen, a bath room, a living area and a front verandah. It's unit cost was estimated as Rs.1.28 million in 2018. Cost of a unit with the same design was estimated as Rs.1.5 million in the same year with the conventional housing construction method.

However, most of the construction materials were imported from China including ALC panels, which are not available in Sri Lanka. Hence, it was necessary to analyze and ensure that all the materials adhere to the recommended standards in Sri Lanka.

Further, the proposed construction method could be reviewed based on 4 phases of construction; 1. Foundation 2. Superstructure 3. Roof structure 4. Finishing works (refer figure 2).

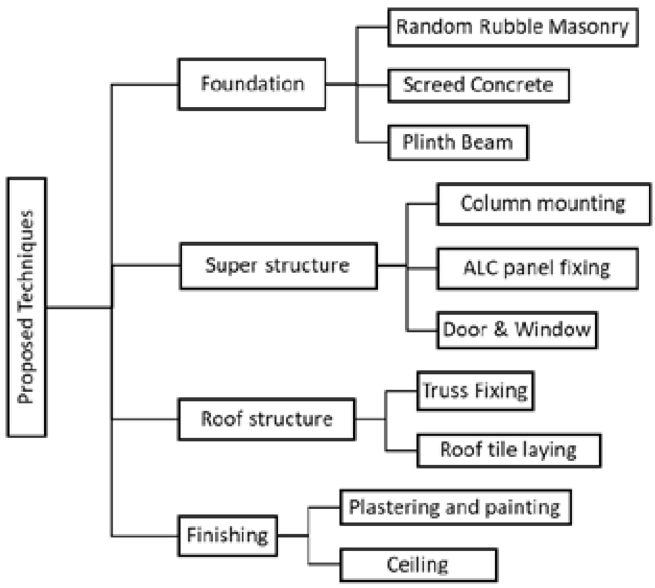


Figure 02: Key phases of the construction

2.1. Foundation

The proposed foundation of the structure does not differ much from the conventional style foundation. Strip type Random Rubble Masonry (RRM) and plinth beam arrangements are the major parts of the proposed foundation to safely transferring the structural load to the ground. Most of the tasks involved such as setting out, excavation, backfilling, and compaction and floor concreting can be directed with minimum technical complexity. In the land condition assessment, significant attention was given to the annual flood level in order to decide the foundation height of a particular house unit.

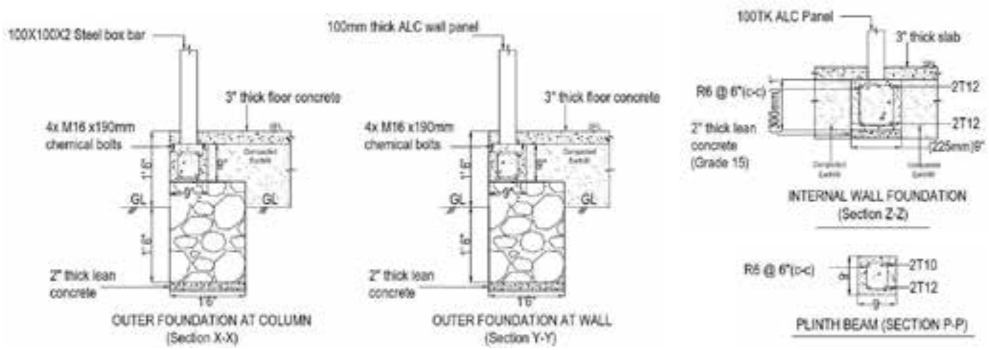


Figure 03: Sectional view of the foundation

2.2. Superstructure

In conventional building construction methodologies, Superstructure works take around 3 times higher duration than substructure (M.Madhu & K.Hemanth Raja, 2017). Therefore, more advanced techniques were introduced to replace conventional methods. Usage of precast panels instead of brick walls produces a substantial time saving as well as a cost reduction. In addition to that, when most of the structural elements are fabricated with lightweight materials, transportation and fixing can be done in an effective manner with less labour requirements. In proposed construction method, there are 3 major criteria in Superstructure such as; 1. Column mounting 2. ALC panel fixing 3. Door and window connection.

Figure 04: Superstructure works

2.2.1. Steel column

A 4''x 4'' Steel column infilled with Grade 25 concrete for 300 mm from the bottom acts as a load - bearing element and also increases the structural rigidity when connected with the ALC panel wall and roof structure. The column is mounted using four M16 x 190 chemical bolts to the plinth beam. C-channels are connected along column height to have a proper connection with the wall. Since most of the column volume is a hollow rectangular section, it is very convenient to erect with a minimum labour force in a short period.

Figure 05: Steel column

2.2.2. ALC panel

The key element of this project is the utilization of Autoclave Lightweight Concrete (ALC) panels as the wall construction material thus replacing the conventional brick or block type walls. ALC technology was invented around the 1920s in Sweden and today, ALC is being used in more than 100 Countries. Autoclaved Lightweight Concrete is cast with fine silica powder, cement, quick-lime and Aluminium powder. ALC structures contain voids around 70% of their volume. The reaction of aluminium powder with quick lime produces gas during the fabrication and entrapped fine gas bubbles reduce the concrete content in the mixture. Since there exists pores in the concrete, it is very light in weight. Comparatively, it is 1/3rd or 1/4th times less in weight than brick structures (Vikas P Jadhao et al, 2013). Shifting and mounting of wall panels can be done more effectively rather than conventional building methods. Moreover, ALC panels are good for sound and thermal insulation and have a superior fire resistance.

In this project, setting out the panel placement after completing the substructure is a crucial part as each of the panels has a predetermined position with respect to the designs and drawings. High water absorption and low compressive strength are the major drawbacks in ALC panels. As the ALC material has a high number of pores, it tends to absorb water quickly. Hence, a proper procedure is required to treat the absorption problems. On the other hand, the compressive strength of this concrete is comparatively low because of the lesser effective area of concrete in order to resist axial forces.

Each ALC panel is having dimensions of 600 mm in width and 3 m in height and the thicknesses of the panels are 100 mm and 200 mm. Column - wall connection is done by fixing the C-channel with the column firmly using nut and bolt connection and the ALC wall is fixed with the C-channel. Roof trusses also rest on the C-channels which are mounted on top of the wall and they are connected using L-connectors on both sides. Panels are connected with each other using tongue and groove joints by applying a special adhesive. In addition to that, 6 mm diameter nails are inserted in a way to create a 30-degree downward inclination between the panel edges which are perpendicularly intersecting to increase the structural rigidity.

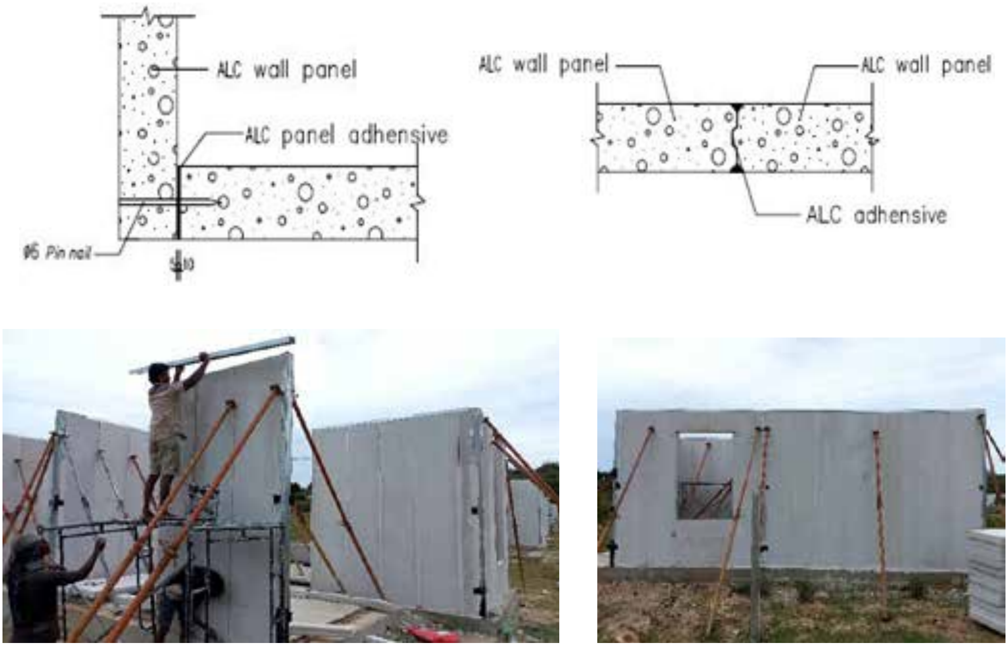


Figure 06: Connection between panels

2.2.3. Roof structure

Roof structure design was concentrated on load reduction so the elements were designed with lightweight materials. Galvanized Light Gauge Steel (LGS) was used to fabricate the truss section and also fibre cement board and PVC materials are used for the ceiling. However, Calicut roof tiles were selected as the roof covering based on the cultural requirements and also by considering the higher temperature conditions in North and Eastern Provinces, even though the weight is significant. Each of the metal elements is expected to comply with the tensile properties as specified in the standards.

Figure 07: Roof structure and connection

2.2.4. Finishing work

Finishing work contains plastering and painting, floor tiling work, ceiling work, electrical and plumbing work, etc. Since paint does not easily adhere to panel surfaces, external plastering and painting are done after preparing the surface with mortar, fibre glass mesh and paint. Internal plastering is done after application of a combination of internal wall putty, fibre glass mesh and paint. The contractor tends to pay more attention to finishing works as it is significantly highlighted by the community-based officials to overwhelm the achievement and attraction.

Figure 08: Roof structure and connection

3. Quality of Materials

In order to ensure durability of structures, it is important to focus on the material quality as well. Hence, substantial effort is being taken to ensure the material quality before usage. The quality of the materials is identified by the material testing results through the relevant testing laboratories.

3.1. Material testing

Since significant quantities of materials are imported, it is vital to ensure that the quality requirements are satisfied before their usage in construction works. Therefore, random samples were collected from all the imported materials and critical parameters were tested in the laboratory to check whether the quality comply with Sri Lanka standards.

Table 02: Materials and testing parameters

Materials	Parameters
Autoclaved Lightweight Concrete (ALC) panel	Compressive strength (dry), Compressive strength (wet), Dry density, Dry shrinkage, Water absorption, Fire performance, Chemical test, Tensile properties of reinforcement bars
Metal purlins (roof trusses) and Structural steel "C" sections and Steel hollow box	Tensile properties, coating thickness, Chemical composition, Cross-sectional dimensions, Nominal thickness, Mass per meter run, Corrosion test for C sections
Fibre cement flat ceiling sheet	Modulus of rupture, Density
PVC indoor ceiling sheet	Thermal stability
Joining and anchoring items	Chemical composition, Dimensional properties
Fiberglass mesh	Unit weight, Nominal opening size, Surface appearance
Ceramic floor tiles	Tolerances for dimensional and surface quality, Water absorption % , Modulus of rupture, Moh's hardness, Co-efficient of linear thermal expansion
Ceramic wall tiles	Adhesion Strength, Compressive strength, Fineness, Cracking, Flow table test, Petrification and setting time
Interior wall putty	Compressive strength, Adhesive strength Fresh bulk density
Surface Mortar	Coating thickness

3.2. Issues with the materials and suggested rectification method.

According to the test results for the first batch, some of the materials failed to satisfy the required standards. Moreover, structurally important parameters like the compressive strength of panels also failed to satisfy the specified standards. Therefore, NBRO as the

Table 3: Material related issues and rectification methods

Material	Failed parameter	Suggested rectification
200 mm thick ALC panel	Dry compressive strength	This material was rejected and Blockwork or Concrete jacketing method was recommended.
	Water absorption	
100 mm thick ALC panel	Water absorption	Waterproofing or plastering with damp proofing paint recommended
C-sections & Steel hollow box	Coating thickness	Anticorrosive paint with SLS or ISO standards as directed by Engineer.

technical consultant, had to propose optimum solutions to overcome these issues. As shown in the table, following materials failed to satisfy the specified standards.

4. Issues in the process of the application in Sri Lanka

Although this project seems to be beneficial, it too has some practical issues during the implementation in the field as a new technology. Following key issues could be highlighted.

Lack of knowledge: Since this technology is unfamiliar in Sri Lankan context of housing construction, it was difficult to carry out the project in a smooth manner. Substantial efforts were required to educate the people with respect to their knowledge level. Prior to the project commencement, awareness sessions were carried out in the Divisional Secretariat office by gathering administrative officers, technical officers, development officers and beneficiaries. Moreover, it was observed that several technical mis understandings arose among the local contractors and beneficiaries regarding the proposed methodologies and technologies.

Transportation & material distribution: Construction sites of this project were located and scattered among the remote areas of Northern and Eastern Provinces. Therefore, an extra effort was required to find the resources for the construction works. Scarcity of water and electricity was significant. On the other hand, many areas were not easily accessible with the available transportation facilities and as a result, time delays occurred.

Local labor: Lack of trained labor to construct houses with proposed new technology affected the progress of the project. Thus, proper skill development sessions should be conducted prior to commencement of the construction to minimize the quality related issues of construction.

Price fluctuations: Key materials like ALC wall panels and light gauge steel sections are imported from foreign countries, hence material prices are subjected to fluctuation depending on the dollar rate fluctuations, and issues like covid 19 pandemic situation impacted project progress significantly due to failures in supply chain in global context.

Material un suitability: As most of the materials were imported from China to this project, it was necessary to check suitability of such materials to the native environment in reference to the project technical specifications. It was a challenging situation for the Engineer to suggest rectifications if any material fails in the laboratory testing. Also, some of the finishing materials like electrical equipment, plumbing, bathroom fittings and wastewater systems got negative feedbacks from the beneficiaries due to the quality related concerns. Thus, developers should ensure the quality of materials as per technical specifications with suppliers prior to importing.

5. Conclusion and Recommendation

Concisely, construction methodology using precast materials paves a revolutionary development towards speedy, low cost and environment friendly construction. However, such new technologies should be introduced adhering to required standards. Further, social acceptability of the proposed new housing technology is important for the successful implementation of a mass scale housing project. Thus, incorporating Local cultural and beliefs in housing construction and prior community awareness are important. Quality assurance of Foreign materials should be paid a significant attention to ensure the quality of final product and sustainability of the project. Skilled labor availability on the proposed new technology is another important factor. Usage of Foreign labor in a Country like Sri Lanka is not that practical, and the use of properly trained local labor is important. In addition, depending on Foreign materials is not a reliable method of material supply as that would considerably affect the success of the project; especially, with the price fluctuations and impacts on supply chain. Thus, more research on new technologies should be promoted to produce required material locally.

6. References

1. Madhu, M. and Hemanadha Raja,K., 2017. Evaluation of precast technology on project profitability (pp.281-286).
2. Vikas, P., Jadhao, Prakash, S., Pajgade, 2013. Influence of Masonry Infill Walls on Seismic Performance of RC Framed Structures a Comparison of AAC and Conventional Brick Infill (pp. 148-153).

Study on the Monetary Impact on Planned Head Office Overhead Due to Contract Prolongation

PBSA Wickramshinghe[1]

[1]Quantity Surveyor, National Building Research Organisation, Sri Lanka

Abstract

Every construction organization is required maintain a head office at a certain location where they can operate, support and monitor their construction project within the country and away from their home land. Generally, organizations recover their head office overheads by including such costs to their tender prices which they are competing to win or their cost estimate proposals of the projects which they are planning to undertake. During the tendering stage, organization management will determine the amount of money or percentage they are planning to recover from that particular project for the intended project duration.

The most common complications confronted by the construction projects are the prolongation of project period and changes in the original scope of work. Due to these common complications, contractor may not be able to recover the proportion of head office overhead which was planned during the tendering stage for the prolonged time period and finally loose the anticipated profit from the project. To mitigate under recovery of head office overhead it is necessary to maintain proper records of these overheads that have been involved with the project. Further, it is necessary to plan and expedite the work during extended time period and subsequently they may be able to recover the planned proportion of head office overhead.

Keywords: Head office overhead, Contract, Prolongation, Cost

1. Introduction

Construction of buildings, road networks, bridges, canals, irrigation systems, dams & etc. are providing necessary support to the other sectors such as education, health, transportation, agriculture & manufacturing industry which are contributing to the economy. Hence, construction industry is considered as one of the main sectors that provide important ingredient for the development of an economy. Therefore, construction industry not only a part of the economy but also provide support to establish required infrastructure facilities to other industries. To achieve the expected economical outcome of an infrastructure development and from construction industry itself, it is necessary to complete the work within the planned time frame and budgeted allocation.

However, many projects experience extensive delays and thereby exceed initial time and cost estimates. Construction projects are complex endeavours, associated with large costs and long duration. A large number of interconnected activities carried out by different project participants need to be carried out during execution of a construction project (Aleksander & Jana, 2018). "Time is money" is the fundamental premise underlying disputes regarding delays to construction projects. A project that has experienced a delay in its expected completion date, from whatever cause, incurs added costs as a result. A significant portion of the costs of the management and support of an on going construction project are directly tied to the overall duration of the construction work. The longer the work goes on, the higher the costs (Andrew, 2015). A "delay" in the construction context can be specifically defined as any failure to complete a specific construction activity within the time planned for it. However, when we think of construction delays that cause added costs and disputes, it is almost always delay to the overall construction contract completion that is being referenced, and not delay to just a single activity or part of the construction process. Delays to individual work activities typically have relatively little or no distinguishable cost. The damages due to delays are primarily incurred when the overall project duration is extended. When assessing the costs and consequences of a particular event that delays some aspects of the construction work, the first step is to assess that event's effect on the project's overall completion schedule (Andrew, 2015). Therefore, to timely completion of projects, it is necessary to act promptly by each party to the contract (employer, engineer or the consultant and the contractor) and hence, finally increase in overall project cost.

2. Literature Review

2.1. What is Schedule Overrun

The problem of projects schedule overruns in the construction industry is a global phenomenon (Sambasivan, 2007). Alkhathami (2005) defines schedule overruns as extra time required to finish a given construction project beyond its original planned duration, whether compensated for or not. According to Assaf & Hejji (2006) schedule overrun as the time overrun either beyond completion date specified in a contract or beyond the date that the parties agreed upon for delivery of a project. It is a project slipping over its planned schedule and is considered as common problem in construction projects worldwide. Delivering projects within the contract stipulated time is one of the yield sticks of measuring a successful project. Despite its proven importance it is not uncommon to see construction projects failing to achieve their objectives (Memon, Rahman & Aziz, 2nd Novermber 2012). However, construction projects schedule overruns have negative impacts to all construction parties including the client. These negative impacts could be due to additional costs incurred by Labour, Material, Equipment, Plants, Project Overheads, Head Office Overheads & etc.

2.2. What are Additional Costs

There are no strict accounting rules on how additional costs are calculated. A general list of additional costs resulting from a project delay includes Labour Costs, Equipment Costs, Material Costs, Subcontractor Costs, Jobsite Overhead Costs & Home Office Overhead Costs (James & Peter, 2000).

In general, there are three definitions that are important when dealing with Head Office Overhead. i.e., Normal Head Office Overhead % is the company's typical head office overhead percentage based on past year audit or accounting, Actual Head Office Overhead % that the Company's actual head office overhead percentage during the year(s) of the project, again based on audit or company accounting and Actual Head Office Overhead % Delay Period where the Company's actual head office overhead percentage solely during the period of the delay (James Z. G., April 2002)

2.3. Determination of Additional Costs

Compensation for prolongation should not be paid for anything other than work actually done, time actually taken up or loss and/or expense actually suffered. In other words, the compensation for prolongation caused other than by variation is based on the actual additional cost incurred by the contractor (Enderbury, 2017).

2.4. Formulas used for calculation of Head Office Overhead

At present there are several formulas that can be used to calculate head office overhead of an organization. Which are namely, Hudson's Formula, Eichleay Formula, (Modified Eichleay Formula Variation 1 & 2), Ernstrom Formula, Manshul Formula, Carteret Formula, Allegheny Formula & Emden Formula (James Z. G., April 2002.)

3. Methodology

3.1. Data Collection

For the purpose of this study, 10 projects have been selected where bids were called using National Competitive Bidding to select a local contractor (Sri Lanka only) those who are having registration for Construction Industry Development Authority (CIDA) SP category. All the selected projects are landslide mitigation projects where soil nailing work as the specialized work. Further, all the projects have been prolonged beyond the initial construction period. Also, initial contract value and initial contract period was not considered for the selection of projects.

From the selected projects, Data such as Initial Contract Price (with the BOQ breakdown of Preliminaries, Measured Work, Provisional Sums & Dayworks), Initial Contract Period from the Contact Agreement. Final Contract Value including Claims was extracted from Final Account agreed by the contract parties (Preliminaries, Measured Work, Variations Provisional Sums, Dayworks, loss of head office overhead, prolongation cost, etc.) and Final Contract Period from the final extension of Time granted by the Employer were collected.

3.2. Data analysis

Out of the formulas available for calculating Head Office Overhead, Hudson's formula was selected to analyse the collected data. Hudson Formula is one of the most widely used formula in the construction industry to calculate head office overhead and it is one of the simplest formulas with only having four (04) variables to be known for calculation of head office overhead. It consumes lesser time duration and provide faster results for making decision. Calculation is based on purely from the data extracted from contract documents and audited reports only and no additional record keeping is required collecting of data.

4. Analysis

4.1. Analysis of Data Collected

Analysis of data collected from the relevant contract documents are consisted of several steps. These are given below.

- Step 01 - Determination of planned head office overhead for the project

$$\text{Initial Contract Price} - \text{Contingencies} - \text{Day Works} - \text{Provisional Sums} = \text{Value of work included Head Office Overhead}$$

$$\text{Planned Head Office Overhead \& Profit} \times \text{Original Contract Price} \times \frac{\text{Planned Head Office Overhead \%}}{(1+\text{Planned Head Office Overhead \%})} = \text{Planned Head office Overhead for the Project}$$

$$\text{Planned Head Office Overhead \& Profit} \times \frac{\text{Original Contract Price}}{\text{Original Contract Period}} \times \frac{\text{Planned Head Office Overhead \%}}{(1+\text{Planned Head Office Overhead \%})} = \text{Planned Head office Overhead per Day}$$

- Step 02 - Calculation of final value of the project including measured work, escalation and claims.
- Step 03 - Analyze and calculation of head office overhead fir most recent claim submitted by the contractor.
- Step 04 - Comparison between the planned head office overhead verses the actual head office overhead recovered.

4.2. Results

Table 1 gives the initial data such as Initial Contract Price, Initial Contract Price, Applied Head office Overhead percentage and total amount of Planned Head Office Overheads to be recovered from the projects and per day amount for each project.

Table 01: Initial Contract Value, Initial Contract Period, Planned Head Office Overhead

No	Project	Initial Contract Price (Rs.)	Initial Contract Period (Days)	Initial Contract Price without Provisional Sums and Contingencies (Rs.)	Applied Head Office Overhead Percentage	Planned Head office Overhead for the Project (Rs.)	Planned Head office Overhead per Day (Rs.)
1	Project – A	96,981,390.00	282	77,831,700.00	15%	10,151,960.87	35,999.86
2	Project – B	135,435,810.00	365	116,022,100.00	15%	15,133,317.39	41,461.14
3	Project – C	85,533,477.25	365	72,264,415.00	20%	12,044,069.17	32,997.45
4	Project – D	152,983,020.00	455	120,877,500.00	15%	15,766,630.43	34,651.94
5	Project – E	182,450,680.00	445	144,995,550.00	15%	18,912,463.04	42,499.92
6	Project – F	52,027,463.66	180	45,207,694.21	20%	7,534,615.70	41,858.98
7	Project – G	61,032,730.50	180	59,192,730.50	20%	9,865,455.08	54,808.08
8	Project – H	52,848,595.00	270	43,795,200.00	20%	7,299,200.00	27,034.07
9	Project – I	19,951,393.13	180	15,575,287.50	35%	4,038,037.50	22,433.54
10	Project – J	19,240,996.50	180	15,649,065.00	25%	3,129,813.00	17,387.85

Table 2 shows gives the data such as Final Contract Value with the breakdown of Preliminaries, Measured Work, Variations Provisional Sums, Dayworks from the Final Account, Final Contract period was obtained from the Extension of Time granted and amount of Head Office Overhead Recovered calculated when the project was completed.

Table 02: Final Contract Value, Prolonged Contract Period, Recovered Head Office Overhead

No.	Project	Final Contract Period with EOT (Days)	Final Value Claimed (Rs.)	Applied Head Office Overhead Percentage	Head office Overhead recovered from the Project (Rs.)	Head office Overhead recovered per Day (Rs.)
1	Project – A	530	70,282,361.10	15%	9,167,264.49	17,296.73
2	Project – B	671	122,171,556.40	15%	15,935,420.40	23,748.76
3	Project – C	603	69,663,063.72	20%	11,610,510.62	19,254.58
4	Project – D	597	186,058,008.06	15%	24,013,015.32	40,222.81
5	Project – E	643	232,531,712.55	15%	29,801,163.34	46,347.07
6	Project – F	518	51,886,668.96	20%	9,828,352.70	18,973.65
7	Project – G	491	39,513,302.16	20%	6,585,550.36	13,412.53
8	Project – H	505	44,554,788.78	20%	7,425,798.13	14,704.55
9	Project – I	180	14,777,507.85	35%	3,831,205.74	21,284.48
10	Project – J	309	16,083,823.87	25%	3,216,764.77	10,410.24

Based on the data collected and results obtained from the analysis of data, all the ten (10) cases/ projects that have been selected can be categorized in to six (06) scenarios. They are as follows;

1. Projects completed within the original contract period and achieve 95% to 100% initial contract value by combination of original scope of work, variations and day works
2. Projects completed within the original contract period and value of work achieve is less than 90% initial contract value by combination of original scope of work, variations and day works
3. Projects completed within the original contract period and value of work achieve is exceeds the initial contract value more than 110% by combination of original scope of work, variations and day works
4. Contract period prolonged more than 25% of the original contract period and achieve 95% to 100% initial contract value by combination of original scope of work, variations and day works
5. Contract period prolonged more than 25% of the original contract period and value of work achieve is less than 90% initial contract value by combination of original scope of work, variations and day works

6. Contract period prolonged more than 25% of the original contract period and value of work achieve is exceeds the initial contract value more than 110% by combination of original scope of work, variations and day works

Based on the six scenarios identified from the table 2, status of the Planned and Recovery of Head Office Overhead are illustrated table 3

Table 03: Status of Head Office Overhead Recovery.

Project	Scenario	Variation in Head Office Overhead Recovery (+ / - / 0)	Variation in Head Office Overhead Recovery per day (+ / - / 0)	Status of the Head Office Overhead Recovery (Over/Under/Equal)
Project – A	S-5	(984,696.38)	(18,703.13)	Under Recovery
Project – B	S-5	802,103.01	(17,712.38)	Under Recovery
Project – C	S-5	(433,558.55)	(13,742.87)	Under Recovery
Project – D	S-6	8,246,384.89	5,570.87	Over Recovery
Project – E	S-6	10,888,700.30	3,847.15	Over Recovery
Project – F	S-4	2,293,737.00	(22,885.33)	Under Recovery
Project – G	S-5	(3,279,904.72)	(41,395.55)	Under Recovery
Project – H	S-5	126,598.13	(12,329.52)	Under Recovery
Project – I	S-2	(206,831.76)	(1,149.06)	Under Recovery
Project – J	S-5	86,951.77	(6,977.61)	Under Recovery

It is clearly evident that project that do not achieve the value of work done equal to the initial contract price will not be able to recover the planned Head Office Overhead from that particular project. To recover Head Office Overhead of such projects is to claim loss of Head Office Overhead due to reduction in scope of work. But to achieve planned Head Office Overhead it is necessary to reduce the time duration spent to complete the reduced scope of work proportionally to the original scope of work & its duration.

Further, there are some projects which was able to recover the planned Head Office Overhead with additional scope of work with extended project duration. But those projects rate of return is negative and return period is high compared to the original scope pf work and project durations. Hence, even though the Head Office Overhead recovery higher than the planned Head Office Overhead its rate of return is much less than the initial rate of return and return period is much higher than the initial return period.

Projects that have over recovered the Head Office Overhead is having longer project duration compared to the initial duration. But their rate of return is higher when compared with the initial rate of return.

5. Recommendations & Further Research

5.1. Recommendations

This research study covered number of aspects related to the head office overhead in construction projects. Head Office Overhead is a key component of contractor unit rate when pricing for a project. If the contractor fails to allocate sufficient percentage or value for the Head Office Overhead, then the contractor might win the tender but will fail in recovering actual Head Office Overhead from the project and hence reduce the profit earnings from that project. Therefore, following recommendations may provide a guideline for the contractors to mitigate the losses occurred due to under recovery of Head Office Overhead from a project.

(a) Proper record keeping system should be operated and maintained to monitor and to calculate variation between planned Head Office Overhead vs actual Head Office Overhead

(b) Work carried out during the prolonged period should be planned accordingly that contractor will mitigate the losses due to over utilization of Head Office Overhead

(c) Progress monitoring should be done more efficiently and effectively so that work will not be fallen behind the schedule

(d) Operation in the head office should be carried out efficiently and effectively by planning the procurement of work, handling the logistics, maintaining proper supply chain management system, and maintaining accurate records which quantity surveyors can be easily accessed

(e) Even though formula gives a value for Head Office Overhead it is not the exact amount of Head Office Overhead expended. Therefore, it is recommended calculated Head Office Overhead based on the actuals

5.2. Areas for Further Research

Based on the problems identified during this study following research areas may be considered by future researchers.

(a) Further study should be conducted to study the behaviour of the Head Office Overhead recovery when construction projects are under going on one of the given scenarios

(b) Systematic method should be developed to maintain Head Office Overhead records and how they have been utilized for projects

(c) Further study should be done to identify any other possible scenarios for projects that may under other than the given six

6. References

1. Aleksander, S. P., & Jana, Š. A. (2018, December 1). Delays in Construction Projects. *Causes and Mitigation*, pp. 1383 – 1389.
2. Alkhathami, M. M. (2005). *Examination of the Correlation of Critical Success and Delay Factors in Construction Projects in the Kingdom of Saudi Arabia.* University of Pittsburgh.
3. Andrew, D. N. (2015). *The Law of Construction Delay, Acceleration & Disruption.*
4. Assaf,, S. A., & Hejji, A. S. (2006). Causes of delay in large construction projects. *International Journal of project management,* 349.
5. Enderbury, C. (2017). *Prolongation Cost Claims - The Basic Peinciples.* London, UK: HKA.
6. James, G. Z., & Peter, V. B. (2000). Pricing Contractor Delay Costs. *Building on the Lessons Learned in Construction Dispute Avoidance and Resolution* (pp. 1 - 11). Chicago: Navigant Construction Forum.
7. James, Z. G. (April 2002.). Calculation and Recovery of Home / Head office overhead. *3rd World Congress* (pp. 5 - 11). Melbourne: International Cost Engineering Council.
8. Memon, A. H., Rahman, I. A., & Aziz, A. A. (2nd Novermber 2012). The Cause Factors of Large Project's Cost Overrun: A Survey in the Southern Part of Peninsular Malaysia. *International Journal of Real Estate Studies, Volume* **7**, 1 - 15.
9. Muhammed, E. A. (2015). Delays in Construction Projects. Researchgate.net, 1 - 21.
10. Sambasivan, M. (2007). Causes and effects of delays in Malaysian construction industry. *International Journal of Project Management,* 517-526.

National Building Research Organisation

11th Annual Research Symposium 2021

INNOVATION GEARED
BUILDING RESILIENCE

3

Technical Session

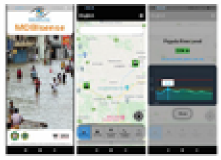
Application of digital technologies for risk management

MOBILISE 3.0

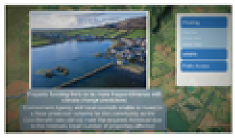
The MOBILISE 3.0 platform is a unique digital platform designed to bring digital innovation to the disaster risk reduction activities conducted by disaster management agencies at local and national level. It has been developed by an interdisciplinary research team in the THINKlab at the University of Salford, in collaboration with government agencies in Sri Lanka, Pakistan and Malaysia.

The MOBILISE 3.0 platform supports a shared risk information space, evidence-based decision making, multi-agency collaboration, community engagement, real-time environmental data monitoring, and early warning system and scenario planning through an easy-to-use visual interface for non-technical stakeholders.

Community engagement



Early Warning



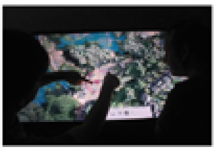
Early Warning

Fast and efficient communication of information at all stages of disaster management is vital to saving lives against natural disasters.

The MOBILISE team is working with government organisations, NGOs and disaster management centres in Sri Lanka, Malaysia and Pakistan to develop technology platforms that help them understand local risks and respond quickly. The MOBILISE 3.0: Early Warning System allows national and local disaster management agencies to digitise their early warning dissemination methods and send efficient warnings through the MOBISense App to communities at risk of flooding, landslides, and extreme weather conditions.

Stakeholder collaboration

Drone environment for landslide mitigation



Drone environment for landslide mitigation

The MOBILISE 3.0 Drone Inspector is changing how its users respond to disasters more effectively and support post-disaster reconstruction efforts. The innovative platform will mean that stakeholders can interpret data more quickly to establish an accurate situational awareness and make better-informed decisions during disaster situations. This environment will allow emergency operation centres to receive live videos from drones and construct a 3D representation of the disaster areas to understand the scale of the impact of a disaster on communities and the physical infrastructure.

Community Engagement

A single catastrophic event can wipe out years of growth through floods, earthquakes and landslides caused by climate change and global warming.

Disaster response and recovery are pivotal in disaster management to ensure communities build back more effectively and make them stronger and more resilient. THINKlab's drone and landslide mitigation digital platform is helping stakeholders do this more effectively around the world. In the United Kingdom, elements of the MOBILISE 3.0 digital platform has been used to help the Royal Society for the Protection of Birds (RSPB) in Lancashire to provide nature-based solutions which are reversing the decline of wildlife.

VISIT US...

The Numerical Simulation Model and GIS Based Analysis For Aranayake Landslide in Kegalle District, Sri Lanka

WMIGTS Senevirathne[1], SSADK Fernando[1], PMGR Bandara[1], HH Hemasinghe[1]

[1]Scientist, National Building Research Organization, Sri Lanka

Abstract

Landslide is one of the most serious natural disasters in Sri Lanka. In the central and southern mountainous area, Landslides such as slope failures, slides and debris flow frequently occur in the monsoon period posing a threat to settlements and other human structures, resulting in death and property damage. The study was focused to model the run-out of a channelize debris flow for Aranayake Debris flow, in order to characterize the sensitivity of the results to the model input parameters and to identify the damage zones of landslides. The Aranayake landslide was used to calibrate a debris flow using Rapid mass movement simulation modeling software, which uses the Voellmy rheology. Rapid mass movement simulation can be a strong modeling tool that can be used in the geographic estimation of the run-out probability, which forms one of the components in the hazard and risk assessment of debris flow. Based on calibrated input values and the available literature, a sensitivity analysis was performed. The Voellmy turbulence coefficient (ξ) was shown to be the most sensitive to the run-out distance and debris flow height, while the rapid mass movement simulation entrainment coefficient (K) was found to be the most sensitive to the total deposit volume. As a result, in study of Aranayake landslide event, friction parameters were found as $\xi = 200\ m/s^2$, $\mu = 0.2$. Hence, the rapid mass movement simulation result covered more than 75% of actual boundary of Aranayake debris flow event.

Key words: RAMMS, Debris flow; Numerical simulation; Voellmy

1. Introduction

Landslides are a common ground surface phenomenon on earth which are mostly triggered by factors that make a slope unstable. Slopes are being unstable the several kinds of changes of geology, topography, soil overburden, drainage, vegetation & etc. Landslides are triggered on such a terrain by rainfall, seismic activities and man-made activities such as roads and building constructions (Arnous, 2010). Even the landslide is a natural phenomenon, recently most of the landslides are happened due to un planned development of peoples like excavations at the base of slopes of toe areas and also natural terrains. Slide, Slope failure, Debris Flow & Rockfalls are the common type of landslides that experience in Sri Lanka. Among them, Debris - flows are common in mountainous areas and present severe hazard due to their high mobility and impact energy. Debris - flow is a form of rapid movement of loose soil, rocks and driftwoods flowed to downstream along valleys. The terminology of debris is defined as a mixture of unsorted material which can contain everything from clay to cobbles, boulders and organic material. Debris flow has low plasticity and produced by mass wasting processes (Hunger et al., 2001). In addition to causing significant morphological changes along rivers and mountain slopes, these flows are frequently reported to have brought about extensive property damage and loss of life. Most Debris - flows in Sri Lanka begin as shallow slope failures on steep slopes with thin residual or colluvial soils, then flow or run out over a long distance with a rapid movement, causing significant damage to people and property, particularly in the flow path and depositional area or debris fan area. For example, the Aranayake debris flow disaster occurred in May 2016 killed more than 127 people. The aim of this research is to reassess the damage area using rapid mass movement simulations (RAMMS) output results and software calibration.

2. Study Area

On the 17th of May 2016, a massive landslide occurred the Aranayake Divisional Secretariat. A total of 127 people were killed, and destroyed a large number of houses. The immediate triggering factor of this landslide was relent less rain for four days from 14th to 17th May, 2016. The landslide occurred in the Northeast facing slope of the Samasariya Hill at Dippitiya.

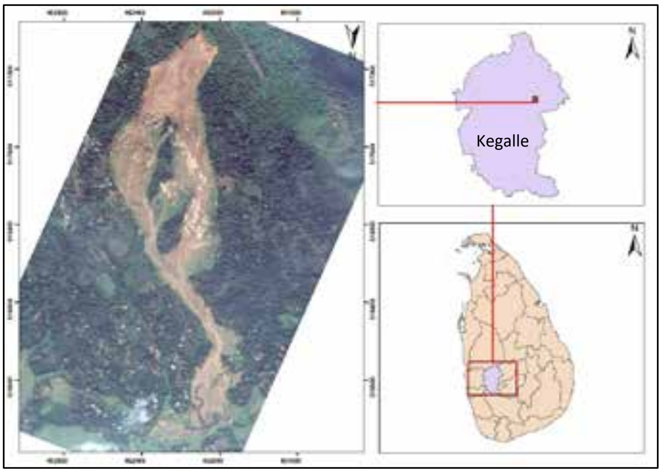


Figure 01: Study area- Aranayake debris-flow event (2016)

3. Methodology

3.1. Flow models

Flow modeling studies are being carried out in order to estimate the potential accumulation zone of future events. (Schraml et al., 2015). The amount of property damage and loss caused by debris flows can be reduced by flow modeling studies. After identifying initiation area, transportation zone and accumulation zone can be identified by the use of flow models. This study used dynamic modeling by using RAMMS software, which uses Voellmy rheology to identify the flow path of debris flow.

3.2. The Software Package RAMMS

RAMMS software uses Voellmy rheology to identify debris flow. By the theory, the flow body travels as a plug with everywhere the same mean velocity (u = (ux, uy^T) consisting of the flow velocity in the x- and y - directions and the height of the flow (h); the friction slope S_f (Pa) is given by:

$$S_f = \mu N + \frac{u^2}{\xi h}$$

$$N = \rho h g \cos(\phi)$$

Where ρ is the density, g the gravitational acceleration, φ the slope angle, the normal stress on the running surface, ρhgcos (φ), can be summarized in a single parameter N. φ is the downslope angle (positive) of the terrain.

The flow law is a well calibrated, hydraulics-based, depth-averaged continuum model and divides the debris flow resistance into a dry Coulomb-type friction (μ) and a viscous resistance (ξ), which varies with the square of the flow velocity.

3.3. Input Parameters

As a first step after selecting the study area, the digital elevation model (DEM) was created using light detecting and ranging (LiDAR) contour data which obtained by survey department using ArcGIS software and input simulation parameters (Grid resolution, end time, dump steps, soil density (ρ) and earth pressure coefficient (λ)) and friction parameters (Viscous turbulent friction (ξ), dry coulomb friction (μ) and cohesion (c)) for RAMMS software. The main input parameters of RAMMS are the total volume of the debris flow and the resistance parameters μ and ξ. Released area would be followed by release height information. The friction coefficients are responsible for the behavior of the flow. Dry coulomb friction (μ) dominates when the flow is close to the end, Viscous turbulent friction (ξ) dominates when the flow is running rapidly.

3.4. Model calibration

Calibration is an important part of modeling debris flow to spatially replicate past event or predict future debris flow. The aim of calibrating model is to adjust the parameters of the model. This paper focus to calibrate model based on Aranayake debris flow event (2016).

RAMMS model calibration was related to the parameters which describe the debris-flow resistance. The dry friction factor (μ) was calculated as the surface slope of debris-flow deposits. The turbulent friction factor (ξ) was chosen and assessed in a range between 150 ms^{-2} and 500 ms^{-2} according to typical values quoted in literature. Table 1 summarized the calibrated input parameters for RAMMS. The adopted cell size 2 m and changing cell size affects the shape of the resultant flow.

The debris flow event, was begun with default friction parameters and then changed the parameters while one parameter is set to be constant. After getting a close simulation result to the actual situation, the parameters are fine-tuned by changing the other friction parameters. In conclusion, best - fitting friction parameter set of the model for the debris flow event were obtained as shown in the following table 1.

Table 01: Calibrated input parameters using the RAMMS model for the Aranayake debris-flow event (2016)

Input parameters	Catchment				
	1(Default)	2	3	4	5
μ (= tan **θ**)	0.2	0.4	0.25	0.15	0.1
ξ (m/s^2)	200	200	150	300	500
Cell size (m)	2	2	2	2	2

4. Results and Discussion

For the calibration of the RAMMS model using Aranayake debris-flow event some assumptions were made as followings,

- SIM resolution (cell size) was made fix through calibration - 2
- Soil density fixed to 2000 kg/ m^3
- Volume of Debris - flow event should be same as all simulation terms

The aim of these assumptions, was to get the best output from sensitivity analysis. Changing Sim resolution/simulation resolution affected the flow of results. Increasing Sim resolution makes larger results. Thus, the simulation resolution was made constant through all five sensitivity simulations. Also, varying soil density and volume of Debris - flow events have an effect on the result. These parameters have set constant to get more accurate results among the test runs.

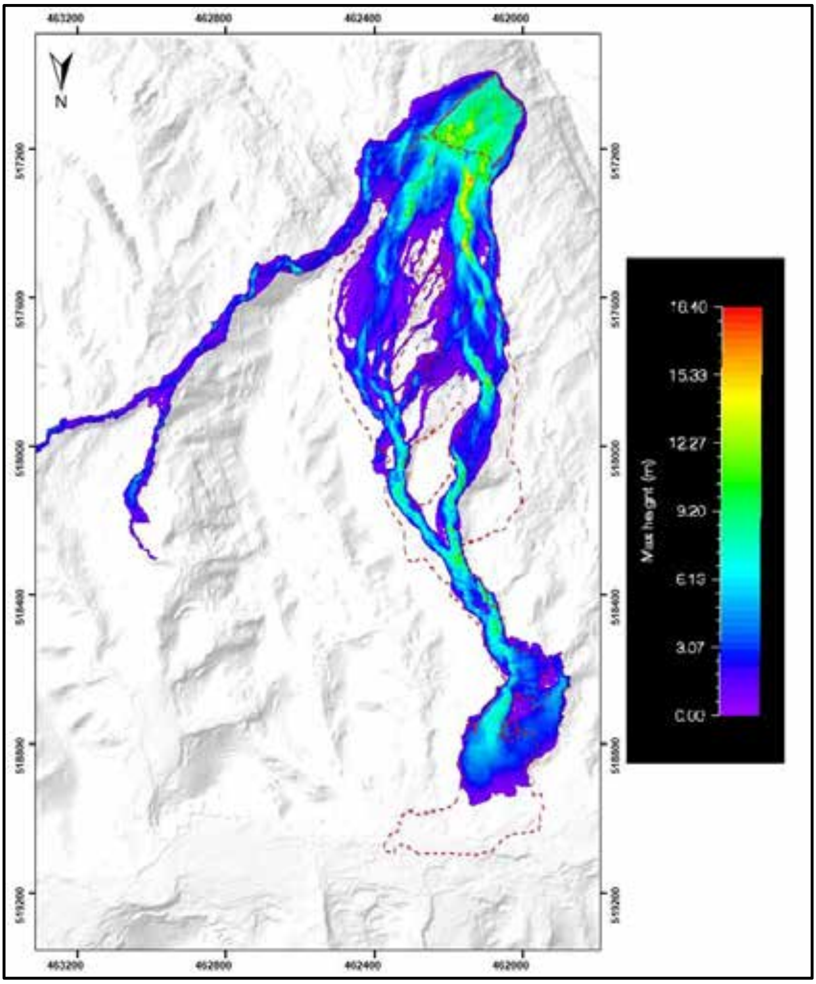


Figure 02: RAMMS model results for Aranayake debris-flow event

The default value of the friction parameter set was not given the best simulation results. Also, the overflow near the initiation area happens because of the spreading or viscous factor becoming increased by the equation of model software. In the actual situation, this overflow has not occurred. For those problems, the model has a barrier function, which will not help in actual cases. At the end of the debris flow area, there are more accumulation of debris, but in actuality, mud like slurry flows without accumulating in that area.

$$\text{Percentage covered} = \frac{\text{Intersect area by simulation}}{\text{Area of the landslide}} \times 100\%$$

$$\text{Percentage covered} = \frac{400{,}899.16\ m^2}{523{,}626.05\ m^2} \times 100\%$$

$$= 76.56\ \%$$

According to the simulation result done in use of above parameters, find out that 76.56% of the landslide area can be covered. In addition, deposition thicknesses and their locations are also given by the simulation result, which is also confirmed in the field.

5. Conclusion and Recommendations

Numerical models benefit from the application in real cases to assist in understanding their potentials and limitations. The simulation results show a significant difference in the actual Debris - flow from the simulated Debris - flow in Aranayake. Because, the sensitivity analysis was done without defining parameters for the case. Collecting actual physical factors from field work such as soil density (ρ), earth pressure coefficient (λ), dry coulomb friction (μ) & viscous turbulent friction (ξ) are recommended to get better results from simulation models and also results should be field verified. RAMMS can be used for other terrains to define friction parameters and simulation parameters individually.

6. Reference

01. Arnous, M. O. (2010). Integrated remote sensing and GIS techniques for landslide hazard zonation: a case study Wadi Watier area, South Sinai, Egypt. Journal of coastal Conservation, 15(4), 477-497.
02. Chen, H., & Lee, C. F. (2004). Geohazards of slope mass movement and its prevention in Hong Kong. Engineering Geology, 76(1-2), 3-25
03. Chiang, S.-H.; Chang, K.-T.; Mondini, A.C.; Tsai, B.-W.; Chen, C.-Y. Simulation of event-based landslides and Debris flow at watershed level. Geomorphology 2012, 138, 306–318.
04. Christen, M., Kowalski, J., & Bartelt, P. (2010). RAMMS: Numerical Simulation of dense snow avalanches in tree-dimensional terrain. Cold regions Science and

Technology, 63(1-2), 1-14.

05. *Cruden, D.M., & Varnes, D.J. (1996). Landslide types and process. In A.K.Turner & R> J. Schuster (Eds.), Landslides: Investigation and Mitigation, Special Report 247 (pp. 36-75).*

06. *Cruden, D.M.; Varnes, D.J. Landslide types and process. Spec. Rep. Trans. Res. Board Nat. Acad. Sci. 1996, 249, 36–75*

07. *Hunger O., Evans, S.G., Bovis, M. J., & Hutchison, J. N. (2001). A review of the classification of landslides of the flow type. Environmental & Engineering Geoscience, VII (3), 221-238.*

08. *Hussin, H. Y. (2011). Probabilistic run-out modeling of a debris flow in Barcelonnette, France.MSc Thesis, University of Twente.*

09. *National Building Research Organization, (2019) Accessed on 2021.09.25*
http://www.nbro.gov.lk.

10. *Scheidl, C.; Rickenmann, D.; Chiari, M. The use of airborne LiDAR data for the analysis of debris flow events in Switzerland. Nat. Hazard. Eart. Syst. Sci. 2008, 8, 1113–1127.*

11. *Schraml, K., Thomschitz, B., Mcardell, B. W., Graf, C., & Kaitna, R. (2015). Modeling debris-flow runout patterns on two alpine fans with different dynamic simulation models. Natural Hazards and Earth System Sciences, 15(7), 1483-1492.*

12. *Tsutsui, K.; Rokugawa, S.; Nakagawa, H.; Miyazaki, S.; Cheng, C.-T.; Shiraishi, T.; Yang, S.-D. Detection and volume estimation of large-scale landslides based on elevation-change analysis using DEMs extracted from high-resolution satellite stereo imagery. IEEE Trans. Geosci. Remote Sens. 2007, 45, 1681–1696.*

13. *Varnes, D. J. (1978). Slope movement types and processes. In special report 176: Landslides: analysis and control (pp. 11-33). Washington D.C: Transportation and Road Research Board, National Academy of Science.*

14. *Vescovi, P. (2006). A GIS-based automated procedure for landslide susceptibility mapping by the conditional analysis method: the Braganza valley case study (Italian Northern Apennines) Environmental Geology, 50, 941-961.*

3D Subsurface Geological Modeling Using GIS and Remote Sensing Data; A Case Study in Galle Municipal Council Area

WGK Madushan[1], MAK Kumari[1], ER Bandula[2]

[1]Scientist, National Building Research Organisation, Sri Lanka
[2]Senior Scientist, National Building Research Organisation, Sri Lanka

Abstract

Geological and geotechnical engineering knowledge and accurate subsurface geological mapping are important for building constructions. In recent years, many detailed subsurface investigations have been planned and undertaken in the Galle Municipal area, Sri Lanka for various infrastructure projects. Recently recorded incidents indicate there is an increasing trend of construction failures and settlements of adjacent pre - existing buildings around these new constructions. Improper understanding of subsurface ground conditions with respect to their properties leads to most of these failures. 3D subsurface modeling, analysis and assessment of soil characteristics are needed to support decision - making processes in all the development projects as part of the urban planning hazard studies. The current paper focused to combine geological and geotechnical in - situ data and remote sensing data with the help of GIS to evaluate the subsurface model. Data from thirty mackintosh testes and boreholes tests were used to construct the 3D soil stratigraphy system for the study area. The Spatial resolution of 1 m Digital Elevation Model (DEM) was used. The proposed methodology of the subsurface model is a combination of an integrated 3D environment and mapping of soil classes at different depths. The results show three major soil stratigraphy units as clay soil, clay sand soil and silty sand soil. Carrying out a detailed geotechnical investigation prior to construction will help in better interpretation and management of the future developments in the Galle Municipal Council area.

1. Introduction

In Sri Lanka, urbanization, which is the growth of the population towards cities and suburbs has been continuously increasing over the last decades. Hence, the rapid urban development, high competition among people and other entities to acquire lands closest to cities led to intense construction activities within close proximity in order to meet the high demand of social and economic needs. As a result, construction of small to high-rise buildings adjacent to existing buildings within the available extent of the land area has become a common scenario. Even though there are many conditions such as its suitability, available infrastructures, and buildable area to be taken into consideration when selecting most importantly its subsurface conditions play an important role (Khan et al, 2021; Boyagoda et al 2016).

Due to negligence of the above mentioned key factors during a proper construction, the recent years indicate a rising trend of construction failures and settlements during the development of various infrastructure projects which eventually have raised a lot of concerns due to their destructive effects on the new constructions as well as on the existing buildings. However, this reveals the lack of knowledge of geological and geotechnical engineering of subsurface conditions around the existing design and improper construction practice without mutual consideration at the designing stage of the construction of a new building adjacent to another (Chenari and Mohafezatker, 2010).

National Building Research Organisation (NBRO) is one of the regulatory institutes in building constrictions in Sri Lanka, which provides guidelines on planning and development activities, standard reports on buildings and constructions, damage assessments and technical solutions and research and development activities on the utilization of areas with technologically problematic soils. Over the last few years, NBRO and other local authorities in Galle have received many complaints regarding building settlements and construction failures in the pre-existing adjacent buildings due to intense construction activities carried out in the Galle Municipal. As per the records of NBRO, an increasing trend of these hazards, and complaints are seen due to a lack of understanding about the subsurface conditions around the sites. Most of these incidents have been reported from Dangedara, Hiribura, Karapitiya, and Koggala Kade areas where initial field investigations have concluded that the possible reasons for most of these failures were differential settlements and angular distortion in the buildings, where the subsurface mostly consists of marshy fillings which are saturated with water bodies (fig. 01).

Figure 01: Adjacent building failures and settlement cases around Galle Municipal area

Votyakov, (1966), studied the effect of an additional settlement to an adjacent building due to its foundation. The results indicate that these failures were mainly depending on the sub surface soil properties, depth and distance of the foundation from one another with the eccentric load. Charles and Skinner, (2004); studied on "Settlement and Tilt of Low Rise Buildings" which occurs on developments made on unsuitable grounds and found out that the concern in foundation design is linked to the shortage of good building land and the consequent necessity of sitting new housing constructions on more marginal ground. Reza et al (2010), conducted a study on adjacent building settlements and concluded that these failures could be overcome by increasing embedment depth of new foundations, provision of deep foundations, and improving load-bearing characteristics of subsoil underneath both old and new buildings.

Since there is no way to overcome these failures without the knowledge of the subsurface and its properties having proper knowledge in geological and engineering geology plays an important role. Even though it may require additional cost to carry out a subsurface investigation, the total investment would be not a waste in case a failure occurs and leads to an extra budget for prevention measures. Test pit excavations, mackintosh tests, Standard Penetration Test (SPT), Dynamic Cone Penetration Test (DCPT) and borehole investigations or other geophysical methods are used for subsurface investigation which are useful to interpret subsurface conditions for design purposes, planning, cost estimate and plan hazard studies prior to any kind of infrastructure project (Anbazhagan, 2018).

Hence in the future, developing a 3D model by in-situ geological and geotechnical data would be very much useful for constructions adjacent to existing buildings, since the lack of homogeneity and difficulties involving in obtaining subsurface data around the area. The proposed 3D model with all layer information will be very effective in representing and interpreting the surface information to enhance visibility, and accuracy for the analysis and design engineering structures which will ultimately be helpful in decision making, hazard and risk assessment studies for future developments around the area (Priya and Dodagoudar, 2017; Kavoura et al 2016).

The focus of the current study is to develop a 3D subsurface geological model using GIS techniques for the Galle Municipal Area, by correlating mackintosh and borehole investigation data for future construction activities to enhance proper knowledge and understanding of the subsurface variability.

2. Study Area

The Galle Municipal covers around an area of 1821 hectares and out of the total land area the consumable area is only about 38% while the rest is covered with forests, plantations, and internal water bodies. The total population is around 140,486 with a growth rate of 0.7% due to inherited living and work, while based on 2012 census data it states that the gross population density is around 26.08 persons per hectare. Further, the city has an average temperature of 26.1°C throughout the year and receives an average rainfall of 2377.9 mm annually mainly from the South-West monsoon.

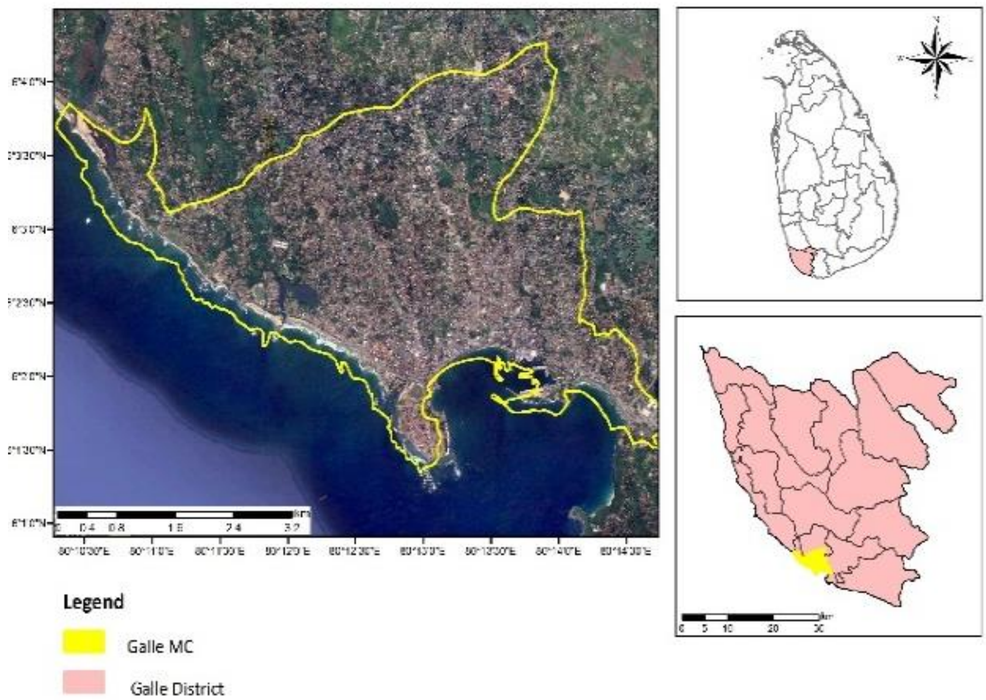


Figure 02: Galle municipal council area (source: Google Earth Imagery (2021)

The municipality mostly consists of low lands with marshes and water bodies but few isolated hills can also be found with heights of 60 - 160 ft (Dissanayake, 2020; Development plan for greater Galle area 2019-2030, Urban Development Authority Galle). In this study, Galle municipal area was selected as shown in Fig. 02 and it is bounded by 6.025330 to 6.062277 latitude and 80.174328 to 80.250181 longitude. Geologically this area consists of highly metamorphosed crystalline rocks such as, Charnokitic gneiss, Calc gneiss and Garnetferous Quartzo Felspathic gneiss (fig. 07).

3. Methodology

Data Collection

In Galle Municipal Area, many geotechnical agencies have carried out several subsurface geotechnical investigations for various infrastructure projects. For this study, nearly 30 mackintosh and borehole investigation data have been used, which were collected from such geotechnical agencies, by mainly prioritizing data collected from areas that have undergone construction failures and hazards (fig.03). Details of these selected locations with corresponding geographical coordinates and sub surface soil stratigraphy layer thicknesses (m) have been obtained by field reports and borehole logs and subsurface soil types were collected from the laboratory test records of field reports, observations made with samples and existing records of borehole logs.

For the development of the Digital Elevation Model (DEM), 1: 5,000 contour data with contours at 1 m intervals which were prepared by the Survey Department of Sri Lanka were used.

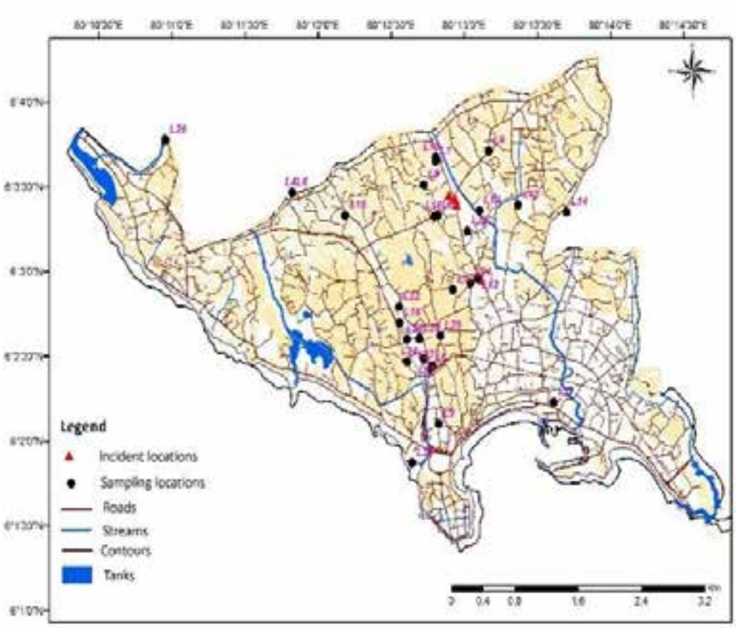


Figure 03: Sample locations and incident locations map at study area

4. Data Processing

Initially, Digital Elevation Model (DEM) was created using Arc GIS by interpolating 1: 5,000 contour data. Then, elevation data of investigated locations have been extracted from the DEM with 1 m spatial resolution by overlaying point map created by corresponding coordinates of the selected locations (Fig.04(a)). The raw data acquired from test reports of each site have been re - arranged using MS Excel with extract top and bottom elevations so that the descriptive information could be logically analyzed for illustrated graphically to develop a 3D model (Fig.04 (b)). For analysis purposes, sub surface soil types were categorized into layers as fill soil, clay soil, clay sand soil, and silty sand soil. This categorization was done as per the laboratory testing indications and field observations which correlate available soil types with their corresponding thicknesses.

The existing information on bearing capacities of soil types extracted from field reports and common Hansen's method (Bowels,1996) used to calculate other borehole SPT values to find bearing capacities. The relationship between mackintosh probe and safe pressure (Hvorslev, 1949) is obtained by the following equation (Eq 1)

$$P = (2860 + 550\,(R - 40)^{\frac{1}{2}}) \times 0.04788.. \quad (1)$$

Where, P = safe pressure (kN/m^2)

R = mackintosh probe penetration resistance in blows/0.3m

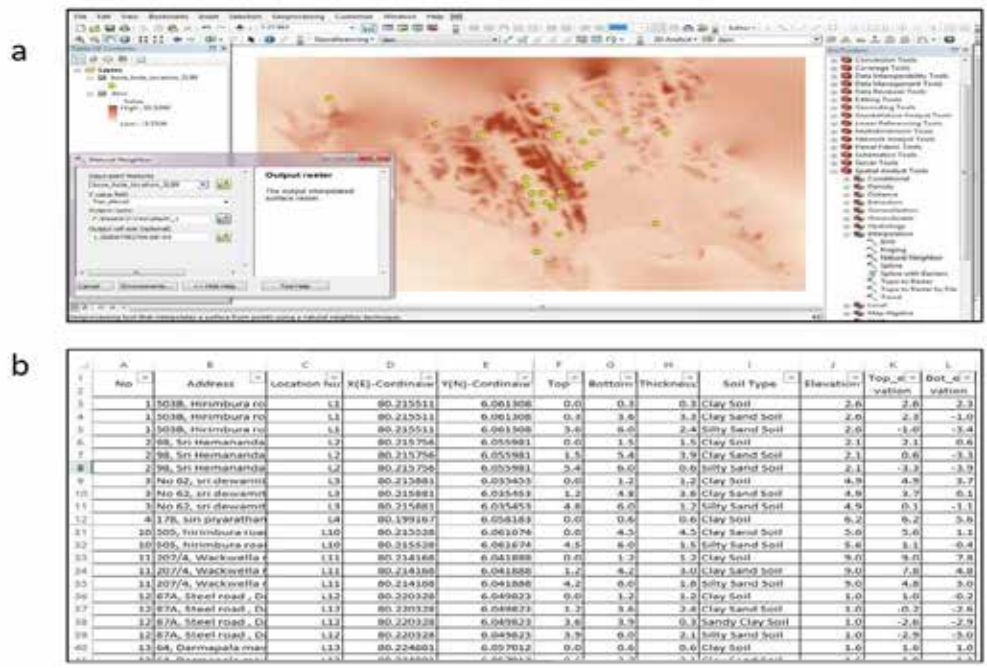


Figure 04: (a) Sample locations associated with DEM; (b) Some of data records viewed in Microsoft Excel

5. 3D Visualization Model

The 3 Dimensional visualization of different sub surface stratum is very useful to understand the relationships in the subsurface. 3D modeling with geotechnical data and information promotes the expert's understanding and further supports in decisions making during the implementation of various geotechnical projects. Hence, 3D modeling has become the upcoming trend in recent years which has helped to minimize the complexities that arise associated with subsurface conditions (Kavoura et al 2016). ArcGIS is a well know software which offers too many possibilities to

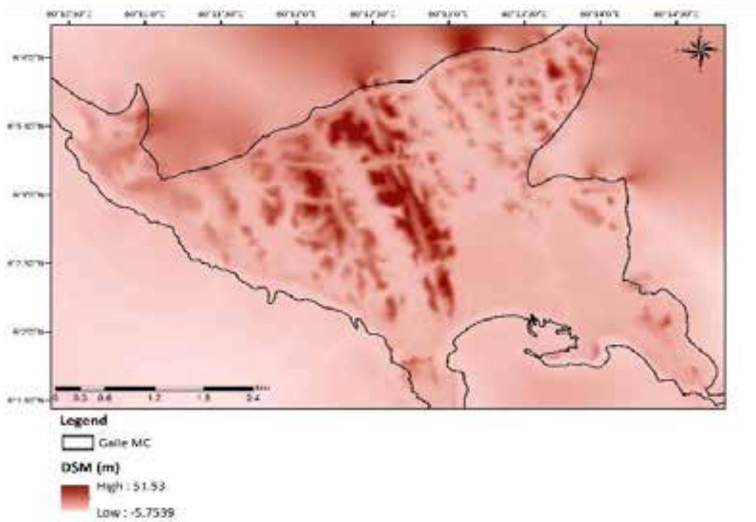


Figure 05: Elevation map of the area with respect to the mean sea level

Interpolate spatial and non-spatial data where the application segment of the ArcGIS package known as ArcScene supports the 3D representation of data. Hence in this study, ArcScene has been used to create the 3D soil stratigraphic model with organized stratum data collected from the Galle Municipal Area.

6. Results

The developed DEM of the Galle Municipal area identifies that the area is generally having undulating plains and low-lying flatlands with few isolated hills. Also, the elevation variation of the area ranges up to a maximum of 50 m elevation with respect to the mean sea level (Fig.05). The resulted 3D model of the study area (Fig.06) depicts that there are 3 main soil stratigraphies namely, clay soil, clay sand soil and silty sand soil with different thicknesses. The topmost layer of the area is a clay soil layer where the thickness varies around 0.3. - 1.8 m. However, in the areas with construction failures and other incidents occur, this thickness varies from 1.2 - 1.8 m. In some locations around Hiribura and Dangedara area some organic matter and peat have been found within this clay layer in small quantities. The second layer consists of clay sand soil with a thickness of 1.2 - 6 m where in areas like Dangedara, Hiribura and Koggalakade the thickness varies from 2.5 - 6 m. Below this clay sand layer the silty sand layer extends up to 0.6 - 4.8m, however available information from the borehole data indicates that this layer extends up to 6 - 10 m or further depths.

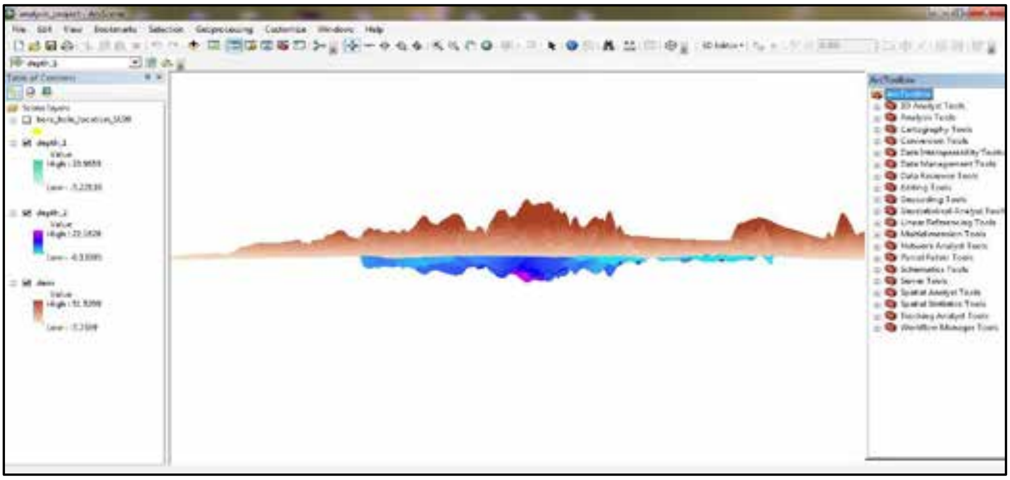


Figure 06: 3D model for Galle Municipal Area.

The geology variation around the area shows that 75% of the hazard incidents were occurred in Charnokite gneiss and Calc gneiss whereas 80% of the hazard incidents were in the Charnokite gneiss. The calculated bearing capacities for clay soil, clay sand soil, and silty sand soil in the study area range 25 - 200 (kN/m^2), 150 - 300 (kN/m^2), and 250 - 350 (kN/m^2). Based on the bearing in silty sand soil layer has a high safe pressure value than the other two layers in the area (Gupta and Trivedi, 2009).

7. Discussion

Most of the settlements and construction failures around the area indicate the lack of understanding about the sub surface conditions, inability to identify the properties of soil stratigraphy with respect to the load bearable or tolerable capacities and embedment depth of these foundations at the initial planning and design stages has mainly led to these failures. The areas of marshy fill lands with saturated water bodies enhance these settlements and failures after the construction. The developed sub surface model supports the prediction of the types of soil and rock availability with their depth variation information. Moreover, this model provides information regarding the requirements of subsurface geotechnical features and also indicates whether a detailed soil investigation is required at the beginning or preliminary planning stages of construction to prevent future hazards. Further, the developed 3D sub surface model will be very effective in planning the developments in existing urban areas. Also it will be helpful for future settlements in existing structures to determine the suitable depths and types of foundations to be used for those proposed structures. In-depth analysis and detailed study of these geotechnical hazards can also ultimately lead to the implementation of rules and regulations to be adhered for safe construction practices in urban areas.

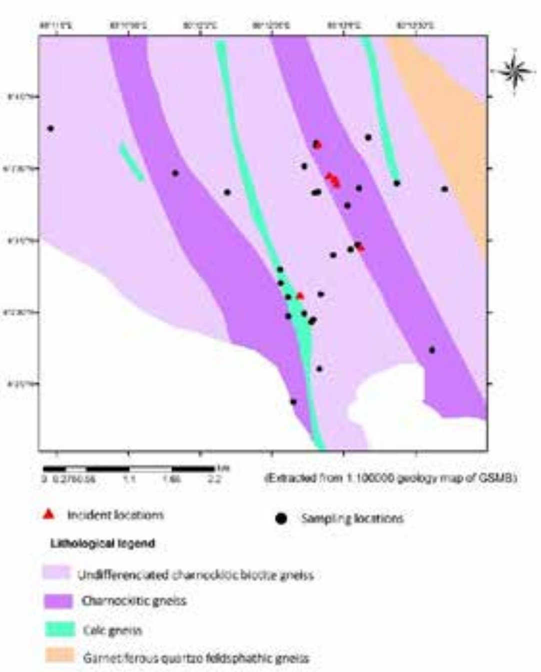


Figure 07: Geology map of the area with sample locations and incident locations.

8. Conclusion

The 3D model developed for the Galle municipal area indicates that the subsurface soil types and the thickness of soil zones vary from one place to another. Hence, due to this variability in properties of sub surface soil stratum, it is suitable and necessary to carry out a detailed geotechnical investigation prior to any kind of construction to implement proper planning, design, and hazardless engineering structures. The developed model can be used as a decision - making tool for future construction activities for the Galle area. However, consideration should also give to generalize specific embedment depth or type of soil strata with the suitable foundation types for constructions, it is wise to carry out further investigations and analysis for these studies.

9. Acknowledgements

We convey our extended gratitude to the Southern Geo-Testing (pvt.) Ltd for providing necessary data and information to encourage this study.

10. References

1. Anbazhagan, P., 2018. Subsurface investigation-integrated and modern approach. In: Krishna AM, Dey A, Sreedeep S (eds) Geotechnics for natural and engineered sustainable technologies: GeoNEst. Springer, Singapore, pp.245–257.
2. Boyagoda, E.M.R.C.L., Kankanamge, L.U.M., and Munasinghe, D.S., 2016. Subsurface geotechnical characterization in Colombo Municipal area and its suburbs. International Symposium 2016-National Building Research Organisation.
3. Bowels, J.E., (1996). Foundation Analysis and Design. McGraw-Hill, New York.
4. Charles, J.A. and Skinner, H.D., 2004. Settlement and tilt of low-rise buildings. Proceedings of the Institution of Civil Engineers-Geotechnical Engineering, 157(2), pp.65-75.
5. Chenari, R.J. and Mohafezatkar, A., 2010. Adjacent Building Induced Settlement Reduction in Residential Constructions. Forensic Approach to Analysis of Geohazard Problems.
6. Dissanayake, D.M.S.L.B., 2020. Land use change and its impacts on land surface temperature in Galle city, Sri Lanka. Climate, 8(5), p.65.
7. Gupta, R. and Trivedi, A., 2009. Bearing capacity and settlement of footing resting on confined loose silty sands. Electronic Journal of Geotechnical Engineering, 14, pp.1-14.
8. Hvorslev, M.J., 1949. Subsurface exploration and sampling of soils for civil engineering purposes.
9. Kavoura, K., Konstantopoulou, M., Kyriou, A., Nikolakopoulos, K.G., Sabatakakis, N. and Depountis, N., 2016, August. 3D subsurface geological modeling using GIS, remote sensing, and boreholes data. In Fourth International Conference on Remote Sensing and Geoinformation of the Environment (RSCy2016) (Vol. 9688, p. 96880K). International Society for Optics and Photonics.
10. Khan, M.S., Park, J. and Seo, J., 2021. Geotechnical Property Modeling and Construction Safety Zoning Based on GIS and BIM Integration. Applied Sciences, 11(9), p.4004.
11. Priya, B.D. and Dodagoudar, G.R., 2017. Building 3D subsurface models and mapping depth to weathered rock in Chennai, south India. Journal of Geomatics, 11(2), pp.191-200.
12. Urban development Authority, 2019. Development plan for grater Galle area 2019-2030, Part-1, Urban Development Authority: Galle, Sri Lanka.
13. Votyakov, I.F., 1966. Additional settlement of a building due to the foundation of an adjacent building. Soil Mechanics and Foundation Engineering, 3(1), pp.36-38.

Importance of Lidar Contour Data for Damage Zone Assessment Using Numerical and Empirical Methods; A Case Study of Aranayake Landslide in Kegalle District, Sri Lanka

PMGR Bandara[1], WMIGTS Senevirathne[1], T Nishikawa[2], T Koike[3]

[1] Geologist, National Building Research Organization, Sri Lanka
[2] JICA expert, Nippon Koei Co., Ltd., Japan
[3]Team Leader, JICA – SABO project, Earth System Science Co.,Ltd., Japan

Abstract

The determination of the damage zone is a vital component of disaster management. When utilized in numerical models such as HyperKANAKO, rapid mass movement simulation, and empirical model such as yellow and red zones method, the resolution of light detecting and ranging data, digital elevation models, slope maps, and hill-shade maps of a terrain play an essential part. In this study, un disturbed terrain prior to the Aranayake landslide in Sri Lanka's Kegalle District was chosen and the above three models were tested in use of light detecting and ranging data, and 10 m interval contour. Both the outcomes of estimating the landslide area and deposition locations by the both numerical and empirical models were compared. As a result, light detection and ranging data specifies a more accurate result for landslide damage zone prediction for the chosen terrain.

Keywords: LiDAR data; hyperKANAKO; RAMMS; Yellow and red zone

1. Introduction

Landslides and slope failures are major and common hazards in Sri Lanka, particularly in mountainous Regions. About 30% of Sri Lanka's land area is considered prone to landslides, while 42% of the total population lives in landslide - prone areas. The number of landslides has recently increased across the Country, owing ostensibly to poor land use planning, uncontrolled building on sloping terrain, historical landslide zones, and change of rainfall intensity due to climate change. In addition fourteen Districts have been identified and affected from landslide occurences during the last decade. Most debris flows in Sri Lanka begin as shallow slope failures on steep slopes with relatively thin residual or colluvial soils, then flow or run out across a great distance with a rapid movement, inflicting major harm to people and property, particularly in debris run - out areas. For example, the Aranayake debris flow tragedy in May 2016 killed hundreds of people following intense rainfall. It accurately illustrates the need for a methodology to anticipate the run - out zone of a slope failure that occurs in mountainous terrain. In Sri Lanka, both direct and indirect methods are now employed to identify the initiation areas of landslides and slope failures. Field surveys and landslide feature identification can be used as direct methods, and landslide hazard zonation mapping (LHZM) can be used as an indirect method. Along with, several numerical and empirical approaches were recently evaluated in Sri Lanka, and among those scenarios, HyperKANAKO, rapid mass movement simulation (RAMMS), and yellow and red zones methods produced substantial results for already occurred landslides. However, high resolution terrain data was employed to achieve those results.

This study aims to identify the importance and advantages of use of light detection and ranging (LIDAR) data for demarcating the possible damage area resulted from both numerical and empirical simulatons.

2. Study Area

In the time period of North-West monsoon, one of the disastrous debris flow occurred in May 2016 in Aranayake in Kegalle District, Sri Lanka as detailed below Figure 1. In the image 2 in Figure 1, the Hill shade has showed the terrain brfore the disaster event and in the image 1 in Figure 1, it is shown the disaster event.

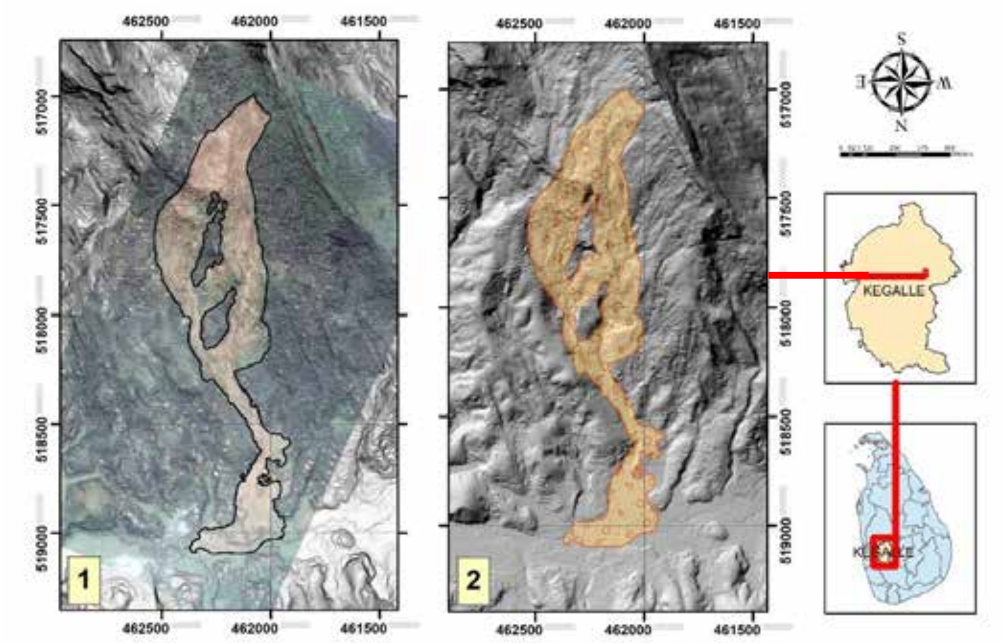


Figure 01: Geographic location of the study area

Province	Sabaragamuwa
District	Kegalle
Divisional Secretarial Division (DSD)	Aranayake
GPS (WGS84)	7.1547360 N, 80.4301490 E
Date of Occurrence	17th May, 2016
Time of Occurrence	4.30 PM
Initiation width	175 m
Initiation depth	10 m
Initiation length	243 m
Initiation Area	40,541.4 m2
Damages	31 deaths / 96 missing
Area of impact zone	523,626 km2

Before the landslide event, the accumulated rainfall totaled 300 mm and 400 mm for 72 hours at Handessa and Weweltalawa rain gauges, respectively. So that, it can be assumed that rainfall has a direct effect on the slope failure.

3. Methodology

3.1. Yellow and Red Zone Concept

The Sediment Disaster Prevention Act was created in Japan in 2001 in order to regulate new development for housing and building reasons, to encourage the relocation of existing houses, and to develop early warning systems for residents living in such hazard zones. According to the Act, a Sediment Disaster Risk Area (Yellow Zone) is defined as an area prone to sediment disaster, and a Special Sediment Disaster Risk Area is defined as an area where there is a higher risk of damage to residential houses and a hazard to residents (Red Zone). The Act defines three categories of sediment disasters: a) debris flow, b) steep slope failure and c) slide. Each disaster type has its own definitions of the Yellow and Red (Y/R) Zones, which were based on the actual state of past sediment disasters and their damage situations occurred in Sri Lanka (Figure 2). Combination of slope failure and debris flow methods of Y/R zones were adapted for this study. In the context of the Sri Lankan condition to use this concept for the Sri lankan terrain, Previous landslide inventory surveys in Sri Lanka identified and categorised four types of landslides: 1) slides, 2) slope failures, 3) debris flows and 4) rockfalls. The categorization method is straightforward and takes into account some of the previously described classification criteria in Varnes's classification of landslides (Varnes, 1978), such as 1) kind of movement and 2) velocity of movement. In Sri Lanka, the classification scheme has also been utilized to identify landslide hazards, as well as risk assessment and management. Slope failures, Slides and debris flows were idenfied according to the landslide inventory and after the characterization of these three types of land movements, yellow and red concept was adapted to the Sri Lankan terrain.

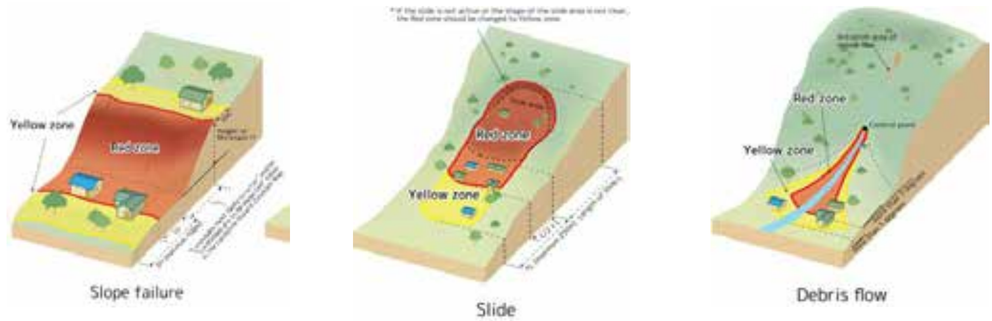


Figure 02: Failure types and damage area demarcation of Y/R concept

(Manual on Risk Assessment for Landslide in Sri Lanka - Yellow / Red Zone Concept, 2021)

3.2. Numerical simulation by Hyper KANAKO

The debris flow numerical simulation in Hyper KANAKO is based on the model described in Takahashi et al., (2001) and Takahashi (2007), and includes equations for momentum, continuance, riverbed deformation, erosion/ deposition, and riverbed shearing stress. In addition, an integrated model (Wada et al., 2008) is used, which takes into account the mutual affects of 1D simulation areas like gullies and 2D simulation areas like alluvial fans. The system employs the same equations as in 1D debris flow models, but with y-axis directional terms added. The continity equation for the total volume of the debris flow is as follows;

$$\frac{\partial h}{\partial t} + \frac{\partial uh}{\partial x} + \frac{\partial vh}{\partial y} = i$$

The continuous equation for determining the debris flow of the k - th grade of particle i,

$$\frac{\partial C_k h}{\partial t} + \frac{\partial C_k hu}{\partial x} + \frac{\partial C_k hv}{\partial y} = i_k C_*$$

For sediment material, two sets of grain size classes are considered: the bigger grain size group, which impacts grid - type SABO dam blockage, and the smaller grain size group, which does not affect blockage. The average grain - size of all sediment components is considered when calculating riverbed deformation (except when establishing the upper point of a grid - type SABO dam), encompassing both bigger and smaller grain-size groups.

The phenomena of x - axis direction (flow - direction) is given by a momentum equation, as follow;

$$\frac{\partial \mathrm{u}}{\partial \mathrm{t}} + u\frac{\partial \mathrm{u}}{\partial \mathrm{x}} + v\frac{\partial u}{\partial y} = \mathrm{gsin}\,\theta_{wx} - \frac{\tau_x}{\rho h}$$

The phenomena of y- axis direction (cross - direction) flow uses a momentum equation as follows,

$$\frac{\partial \mathrm{v}}{\partial \mathrm{t}} + u\frac{\partial \mathrm{v}}{\partial \mathrm{x}} + v\frac{\partial v}{\partial y} = \mathrm{gsin}\,\theta_{wy} - \frac{\tau_y}{\rho h}$$

The equation for determining change in bed surface elevation is as follow;

$$\frac{\partial y}{\partial t} + i = 0$$

In equations mentioned above, h is flow depth, u is x-axis direction flow velocity, v is y-axis direction flow velocity, c_k is the k-th sediment concentration by volume in debris flow, z is bed elevation, i_k is the k-th sediment erosion/ deposition velocity, ρ is gravity acceleration, ρ is interstitial fluid density, θ_{wx} and θ_{wy} are the flow surface gradients in the x-axis and y-axis directions, C_* is sediment concentration by volume in the movable bed layer, and τ_x and τ_y are the riverbed shearing stresses in the x-axis and y-axis direction, respectively.

A field survey was undertaken as the first phase in the simulation process to estimate the volume of unstable sediment, and then field data was analyzed and processed for the simulation to acquire the parameters. Using 10 m interval contours and LiDAR data, two digital elevation models (DEMs) were generated. After field verification and utilizing morphological data from the actual landslide, the initiation area of the debris flow was determined. The 1D and 2D areas were configured to propagate the flow path and depositional area, and the simulation was run with the following input parameters (Table 1).

Table 01: Table showing the input parameters in HyperKANAKO simulator

Item	Unit	Value
Calculation time	sec	1800
Time interval of calculation	sec	10
Mass density of sediment	kg/m^3	2,650
Minimum flow depth	m	0.01
Internal friction angle	Deg	37
Thickness of 2-D plane unstable sediment	m	0
Fluid density	kg/m^3	1,477
Sediment concentration	-	0.38
Landslide Volume	m^3	232,000
Duration of debris flow	sec	80
Peak flow rate	m^3/s	5800
Representative particle diameter	m	0.237

3.3. Numerical simulation by Rapid Mass Movement Simulation (RAMMS)

RAMMS is a reliable numerical simulation tool yielding run out distance, flow heights, flow velocities and impact pressure of dense flow snow avalanches, hillslope landslides and debris flows. It has been developed by the Swiss federal institute which applies the Voellmy rheology will be used to model the run-out of the debris flow. The physical model of RAMM Debris Flow uses the Voellmy friction law. This model divides the frictional resistance into two parts: a dry-Coulomb type friction (coefficient μ) that scales with the normal stress and a velocity squared drag (coefficient ξ). The frictional resistance S (Pa) is then,

$$S_f = \mu N + \frac{u^2}{\xi h} \qquad N = \rho h g \cos(\phi)$$

where ρ is the density, g the gravitational acceleration, φ the slope angle, the normal stress on the running surface, ρhgcos(φ), can be summarized in a single parameter N. φ is the downslope angle (positive) of the terrain.

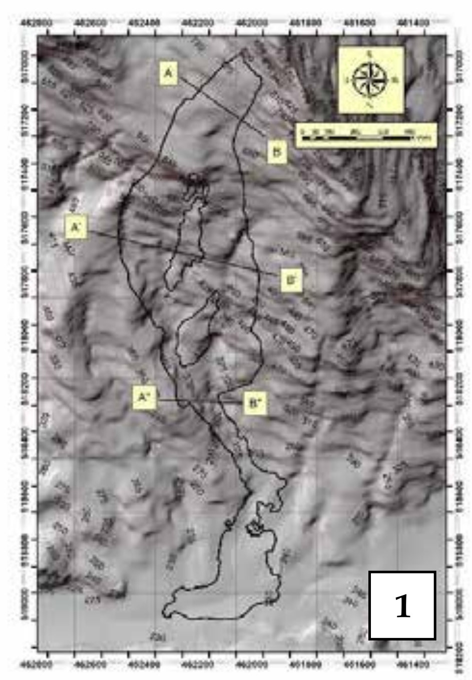
To input friction parameters to model sensitivity analysis was done before the initial study area simulation. After the sensitivity analyisis by previously occurred debris-flow event the friction parameter set was selected to the study area catchment. Then those friction parameters were used to simulate the Aranayaka debris-flow event by using LiDAR data DEM and 10 m contour interval DEM. The simulation parameters and friction parameters for the simulation following in Table 2.

Table 02: Input parameters used in RAMMS model simulation

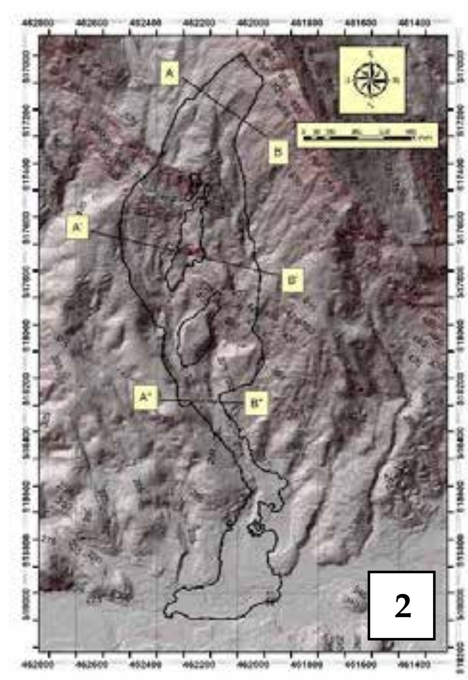
Item	Unit	Value
Sim resolution	m	1
End time	s	1,000
Dump Step	s	5.00
Density	Kg/m^3	2,000
Lambda	-	1.00
Momentum	-	5%
Dry coulomb friction	-	0.4
Viscous turbulent friction	m/s^2	200
Landslide Volume	m^3	232,000
Release Depth	m	5-7

4. Results and Discussions

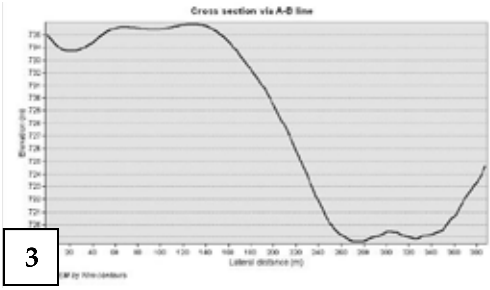
The DEMs which are created from 10 m interval contours and LiDAR contours are compared to observe the difference between terrain. Following images in the Figure 3 showed a significant difference defining detailed terrain from LiDAR contour data.



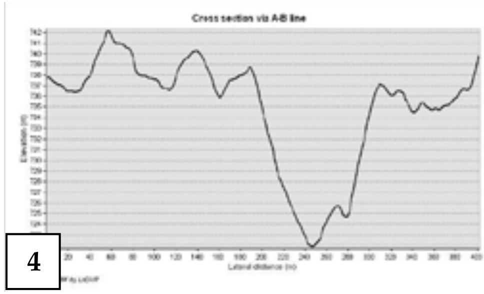
Hillshade prepared by 10 m DEM



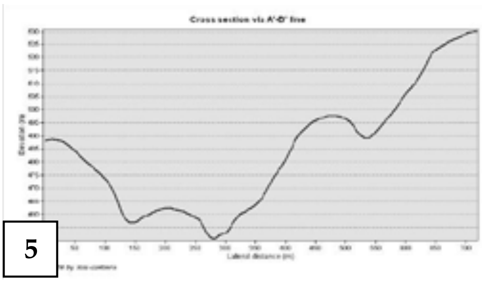
Hillshade prepared by LiDAR data



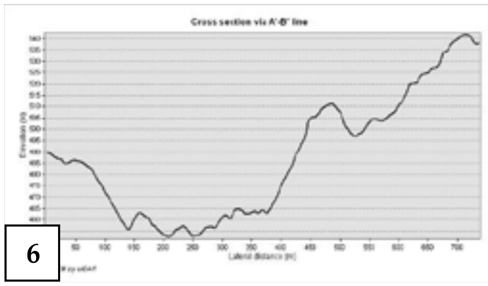
Cross section via A-B line based on 10m contour data



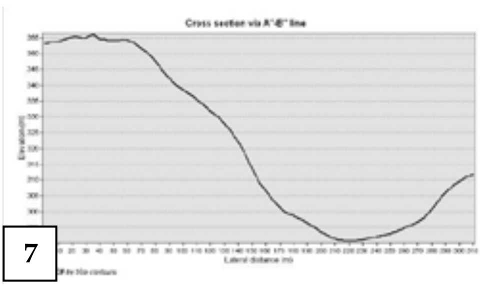
Cross section via A-B line based on LiDAR data



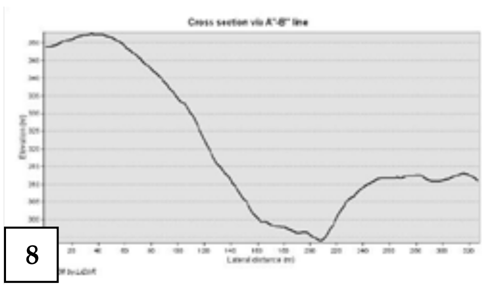
Cross section via A'-B' line based on 10m contour data



Cross section via A'-B' line based on LiDAR data



Cross section via A"-B" line based on 10m contour data

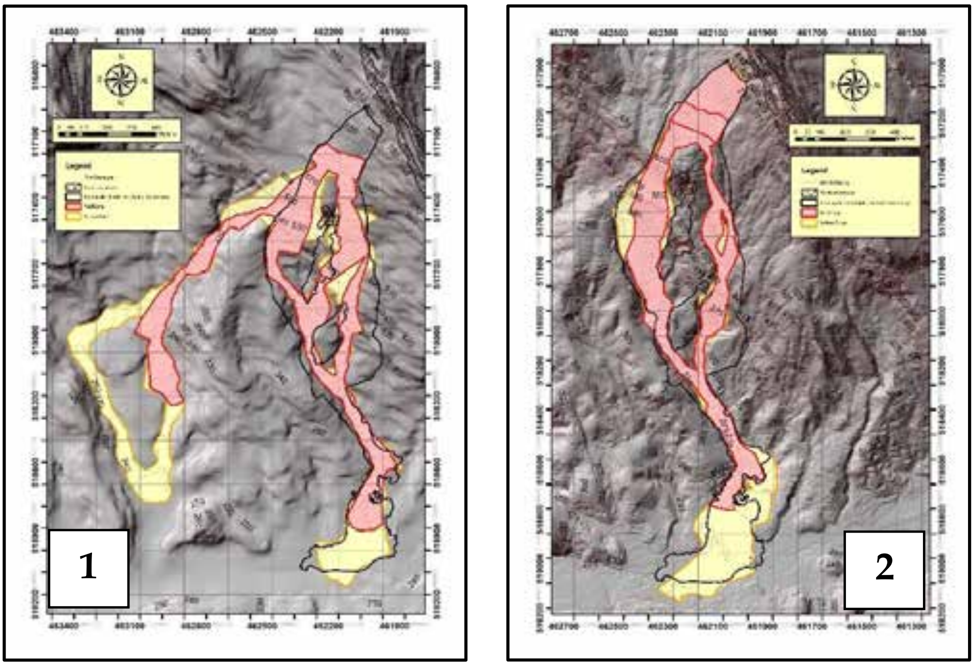


Cross section via A"-B" line based on LiDAR data

Figure 03: DEM comparision and cross sections comparision

In the images 2 in Figure 3, there is an significant difference than the image 1 which shows almost every morphological feature such as valleys, gullies & ridges can be clearly obsereved as the resolution in the hillshade which was generated from the LiDAR data. Based on the resolution, it can be assumed that LiDAR represents the actual condition of the terrain. Further, three cross sections were compared on the each DEMs. Almost all the morphological cross sectional feature was displayed by LiDAR data showing the rough terrain as in the real condition (Images 3 to 8 in Figure 3).

Then empirical model called Y/ R zones was applied to the area, considering the initiation area as in the actual condition. Since the Aranayake landlside is considered as initiated from a slope failure and then flown down as a debris flow, combination of debris flow method and slope failure method of Y/ R zones concept wasa applied. Exceeding the exact the same procedure of Japanese method of Y/ R zones, debris flow method was drawn from the slope failure lower boundary. This method was applied to both 10 m interval contours and LiDAR data (Figure 4). In the image 1 in Figure 4, the estimated result showed an exaggerated result spreding over the nebour valley where the actual event was not spread. But in the image 2 in Figure 4, it has shown a better result covering 74% of actual landslide area. In addition, there is no over flow in the image 2 in Figure. Based on this approach, use of LiDAR data for estimation purpose of the damage zone is vital.

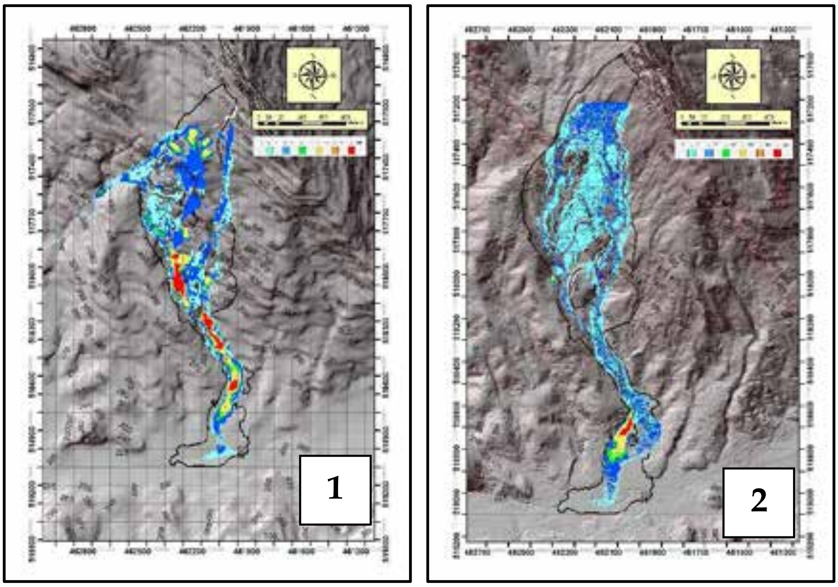


Y/R zone drawing in use of 10 m interval contours

Y/R zone drawing in use of LiDAR contours

Figure 04: Y/R zone drawings of the Aranayake landslide area

Using the paramaters in the Table 1, HyperKANAKO simulation was performed for both DEMs which are generated from 10 m contours and LiDAR contors. HyperKANAKO result in image 1 of Figure 5 based on DEM generated from 10 m contours showed an over flown result compared to the actual landslide. But in the HyperKANAKO result in image 2 of Figure 5 which has performed on the base of DEM generated from LiDAR data showed an appropriate result withour an over flow (Figure 5). In addition, deposition area has been predicted almost correctly in the image 2 of Figure 5.

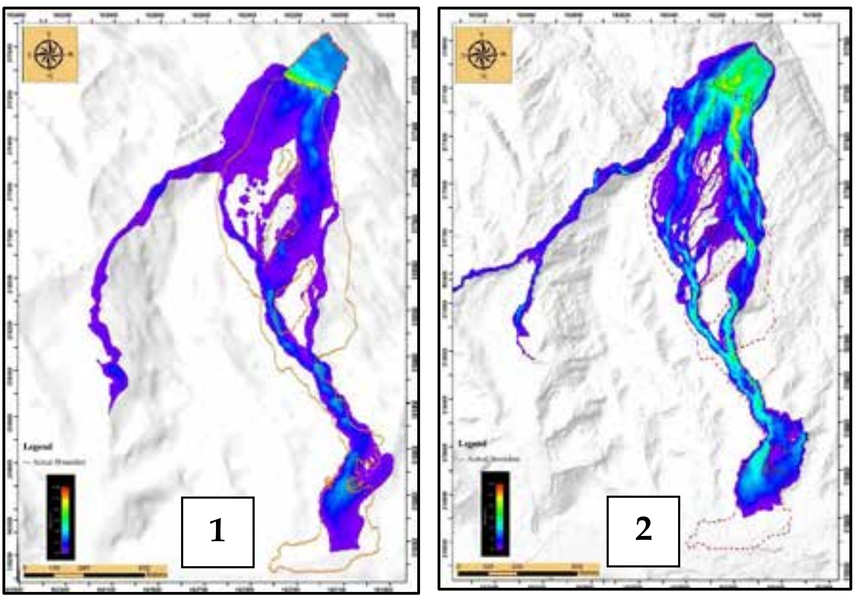


HyperKANAKO result in use of 10 m interval contours (1,800 s)

HyperKANAKO result in use of LiDAR contours (1,800 s)

Figure 05: HyperKANAKO results in use of parameters in Table 1 for both DEMs

In use of the parameters in the Table 2, both DEMs which have generated from 10 m and LiDAR data were utilized in RAMMS. Both results showed an exaggerated results (Figure 6).



RAMMS result in use of 10 m interval contours (1,800 s)

RAMMS result in use of LiDAR contours (1,800 s)

Figure 06: RAMMS results in use of parameters in Table 2

However higher amount of details of deposition thickness over the landslide area can be obsereved in the image 2 of Figure 6 which is also confirmed in the field carried out in the Aranayake landslide area. High resolution deposition thickness can be generated in RAMMS with the aid of LiDAR data as base data. However with the base of DEM created from 10 m contour data, it provides a smooth result of deposition which doesn't match the actual condition (Figure 6).

In both empirical and numerical simulations permofrmed, 100% of the actual damage zone of landslide area can not be predicted in the case of Aranayake, since the Aranayake landlside has been occurred in three steps and after the 1st event the terrain is modified and debris of other two events follow the modified terrain. In this case, spread area could be enlarged rather than the spread over the natural slope. In any of simulations of this study can not be performed for such an case and under estimations can be expected. However the simulation results permforemd in all three methologies in use of LiDAR data has shown appropriate results predicting over 50% area of the actual event with almost accurate deposition thickness data.

5. Conclusions and Recommendations

Accurate debris flow disaster prediction can mitigate damages and guide future zoning, land use, and development plans. To accurately forecast debris flows, the empirical model was integrated with past debris flow records. Both the empirical model and the numerical simulation produced good results in predicting the debris flow event, implying that the both methods can be utilized to quickly and effectively identify debris flow hazard zones and estimate possible damages using LiDAR data. However, Each simulation result should be field verified with the assistance of a landslide specialist.

6. Acknowledgements

The study was carried out as part of the SABO project, a collaboration between JICA and NBRO aimed at increasing capacity to conduct site - specific hazard mapping and risk assessments, developing landslide early warning systems at the Local level, and implementing risk assessments of landslide disasters to land use planning and development control. The authors would like to thank JICA and NBRO for their technical assistance in completing the research.

7. References

1. Christen, M., Kowalski, J., & Bartelt, P. (2010). RAMMS: Numerical Simulation of dense snow avalanches in tree-dimensional terrain. Cold regions Science and Technology, 63(1-2), 1-14.
2. Hussin, H. Y. (2011). Probabilistic run-out modeling of a debris flow in Barcelonnette, France. MSc Thesis, University of Twente.
3. JICA. (2016, June). Aerial Survey report on inundation damages and sediment disasters. https://www.jica.go.jp/srilanka/english/office/topics/c8h0vm00006ufwhl-att/160615.pdf

4. Manual on Risk Assessment for Landslide - Yellow / Red Zone concept (1st ed., Vol. 1). (2021). National Building Research Organization (NBRO) and Japan International Cooperation Agency (JICA).
5. Nakatani, K., Iwanami, E., Horiuchi, S., Satofuka, Y., & Mizuyama, T. (2012). Development of "Hyper KANAKO", a debris flow simulation system based on Laser Profiler data. In Proceedings of 12th Congress INTERPRAEVENT (pp. 269-280).
6. Nakatani, K., Wada, T., Satofuka, Y., and Mizuyama, T. (2008). Development of "Kanako", A Wide Use 1-D and 2-D Debris Flow Simulator Equipped with GUI., WIT Transactions on Engineering Sciences, 60, 49-58.
7. Schraml, K., Thomschitz, B., Mcardell, B. W., Graf, C., & Kaitna, R. (2015). Modeling debris-flow runout patterns on two alpine fans with different dynamic simulation models. Natural Hazards and Earth System Sciences, 15(7), 1483-1492.
8. Takahashi T (2007) Debris flow: Mechanics, Prediction and Countermeasures. Taylor & Francis, Leiden, CRC Press, London, UK.
9. Takahashi T, Nakagawa H, Satofuka Y, et al. (2001) Flood and sediment disasters triggered by 1999 rainfall in Venezuela: A river restoration plan for an alluvial fan. Journal of Natural Disaster Science 23: 65-82. Available online: http://www.jsnds.org/jnds/23_2_2.pdf (Accessed on 13 October 2021).
10. Varnes, D.J., 1978, Slope movement types and processes, in Schuster, R.L., and Krizek, R.J., eds., Landslides Analysis and Control, Special Report 176: Washington, D.C., Transportation Research Board and National Academy of Sciences, p.11–33.
11. Wada T, Satofuka, Y, Mizuyama T (2008) Integration of 1- and 2-dimensional models for debris flow simulation. Journal of the Japan Society of Erosion Control Engineering 61(2): 36-40. (in Japanese with English abstract).

Real-Time Assessment of Fine Particulate Matter Levels in Urban Areas of Sri Lanka

HDS Premasiri[1], NDC Lakmal[2]

[1]Director, Environmental Studies and Service Division, National Building Research Organisation, Sri Lanka

[2]Scientist, National Building Research Organisation, Sri Lanka

Abstract

According to the WHO, 9 out of 10 people breathe air with high levels of pollutants that exceeds WHO guidelines. Highest exposures were recorded in low and middle income Countries, resulting about 4.2 million annual deaths. However, most developing Countries are unaware of their exposure to high pollution conditions as they do not possess air quality monitoring (AQM) networks due to the high cost involved. Sri Lanka, although categorised as a middle - income Country, also yet to establish appropriate real - time AQM network to assess the air pollution risk and exposure levels.

This paper aims to assess the exposure levels and the risk in terms $PM_{2.5}$ and PM_{10} in urban areas of Sri Lanka. A real-time continuous Particulate Matter $PM_{2.5}$ and PM_{10} monitoring program was initiated in 2019 at a few selected urban areas of Sri Lanka. The program was further extended into 15 urban areas in 2020. The $PM_{2.5}$ and PM_{10} levels were recorded continuously to assess hourly, daily and annual average exposure levels and results were analysed to assess the risk of exposure compared to national and US standards.

The results indicated $PM_{2.5}$ and PM_{10} levels drastically fluctuate certain hours of the day, peaking during traffic hours and transboundary period. Inparticular, $PM_{2.5}$ levels exceeded US and national standards in Colombo urban areas during transboundary period. However, daily average levels of $PM_{2.5}$ and PM_{10} levels increase in other urban areas during transboundary pollution, but average standard of US and national did not exceeded. Therefore, low - cost real - time monitoring network is highly favourable as it collects and transmits data to a central point through IoT platform, simultaneously. The data can be used for decision - making purposes.

Key words : Air quality, $PM_{2.5}$ and PM_{10}, Urban, Exposure levels

1. Introduction

Air pollutants such as Particulate Matter (PM), Sulfur dioxide (SO_2), Nitrogen oxides (NO_X), Ozone (O_3), Carbon monoxide (CO), Hydro Carbon (HC) and heavy metals are the criteria pollutants that could lead to harmful impacts for human and other living organisms. Combustion of fossil fuels for various purposes such as transportation, power generation and etc. accounts for generating high amount of these air pollutants. Most of these pollutant sources are concentrated around urban areas rather than in rural areas. In addition to air quality degradation, Carbon dioxide (CO_2), Methane (CH_4), Chloro-Floro Carbon (CFC), Nitrous oxide (N_2O) are known as climate and environmentally damaging pollutants that create Global level impacts.

Urban air pollution has identified as the most serious cause of environment related adverse impacts on human health, materials, vegetation and visibility. The associated risk of air pollution is typically depend on the level of pollutant and the exposure periods. Furthermore, rural residential areas are healthier than the urban residential areas because urban residents are exposed to relatively high air pollution conditions for a longer period. Also, scientific studies indicate that around 91% of the world's urban population lives in places where air quality levels exceed the World Health Organisation (WHO) limits (WHO, 2016). Even though ambient air pollution affects both developed and developing Countries alike, low and middle - income Countries experience the highest - burden, where the greatest toll is seen in the Western Pacific and South-East Asia Regions (Nguyen Cong Thanh, 2019). According to the health authorities in Sri Lanka, over 45% of admission of children to hospital and about 8,000 people died in each year due to air pollution related diseases (Withanage, 2019). It is a considerable challenge to identify these health impacts in urban and other areas due to limited availability of ambient air pollution levels.

However, most of the low - income Countries do not possess scientific evidences on ambient air pollution levels by the type of pollutants and exposure period, as well as the sources of the pollutants due to lack or resources, equipment and systems. Most often the reason for not having proper air quality monitoring (AQM) network is the high cost involved in monitoring. In Sri Lanka, continuous AQM network covering all provinces and Districts of the Island is yet to be established.

Short and long-term air pollution assessment studies have identified PM as the key air pollutant commonly encountered in Sri Lankan urban areas. Exposure to PM has been linked with a wide range of serious health effects such as asthma and cancers. According to the outcome of a study conducted in Sri Lanka, significant associations between $PM_{2.5}$ and PM_{10} levels and increased risk of respiratory disease hospital admissions. A 10 $\mu g/m^3$ increase in $PM_{2.5}$ and PM_{10} were associated with an increased risk of respiratory disease hospitalization by up to 1.95 % and 1.63%, respectively. The same study shows that the high air pollution period, a high - rate ratio was observed for male respiratory disease hospitalization compared to female respiratory disease hospitalization. The reason for this finding might be males spending more time outside during the high air pollution period. (Priyankara et al., 2021). All results presented above indicate high exposure to air pollution in Sri Lanka is correlated with the hospital admission and deaths, which are known to show the diseases of biological plausibility. It indicates the requirement of reliable air quality and health data to developed effective health and environment policies in the Country.

Since one of the most critical air pollutants in urban areas in Sri Lanka is PM, this paper aims to the monitor $PM_{2.5}$ and PM_{10} in selected urban areas using low cost, real-time air quality monitoring sensors. The data were analysed by comparing hourly and daily average concentrations to assess the short - and long - term exposure levels of PM.

2. Methodology

Short and long term variations of $PM_{2.5}$ and PM_{10} at selected urban areas were monitored during this study. Real - time monitoring sensors were located in urban areas of Colombo, Kurunegala, Puttalam, Anuradhapura, Jaffna and Vavuniya. These urban areas were selected due to the critical air pollution situation faced during the North-East monsoon period of 2019 due to transboundary air pollution. All selected sites are the meteorological monitoring stations in each urban area that satisfied the sampling criteria. The selected sites summarised in Table 1 and Figure 1.

Figure 01: Locations Map in Urban areas

Urban area	Location
Colombo	Department Meteorology
Anuradhapura	Department Meteorology
Vavuniya	Department of Meteorology
Kurunegala	Provincial Environmental Authority
Jaffna	Department of Meteorology

Figure 01: Locations Map in Urban areas.

The real-time air quality monitoring units were installed in each selected site in a special type of shelter with a height of 2.5 m to minimise air movements. Overview of sampling unit installed at sites are shown in Figure 2 to Figure 6.

Figure 02: Installation of Monitoring Unit at Colombo Urban Area

Figure 03: Installation of Monitoring Unit at Kurunegala Urban Area

Figure 04: Installation of Monitoring Unit at Anuradhapura Urban Area

Figure 05: Installation of Monitoring Unit at Vavuniya Urban Area

Figure 06: Installation of Monitoring Unit at Jaffna Urban Area

All monitoring units were validated with standard Beta attenuated particulate monitoring techniques before installed at sites. PM concentrations and other data such as Temperature, Humidity and Atmospheric Pressure, etc. were measured at a 5 seconds interval and saved to a micro - SD memory card. This monitoring sensor units can communicate remotely with an IoT platform and the equipment sent data to a server computer through a static IP address in every 5 seconds and the data were then stored in a central database after quality controlling.

3. Results and Discussion

Data files from all urban areas (January 2021 - September 2021) were downloaded from the server computer. These contain an hourly quality control (QC) flag and only data which passed QC checks were used. A sample data file downloaded from the server computer including date, time, $PM_{2.5}$ level, particulate counts, PM_{10} level temperature, relative humidity & etc. are shown in Table 2.

Table 02: Row datasheet downloaded from the server

	A	B	C	D	E	F	G	H
1	Time	CO2	PM1	PM2.5	PM10	T	H	P
2	2021-11-24T14:18:07+05:30	533	9	18	29	27.5	76	1007.4
3	2021-11-24T14:18:09+05:30	534	9	18	29	27.6	74	1006.9
4	2021-11-24T14:18:10+05:30	532	8	16	26	27.5	75	1006.6
5	2021-11-24T14:18:12+05:30	532	8	16	26	27.5	75	1006.5
6	2021-11-24T14:18:13+05:30	532	8	16	26	27.5	76	1006.7
7	2021-11-24T14:18:15+05:30	532	8	17	27	27.4	75	1007.2
8	2021-11-24T14:18:16+05:30	531	8	17	27	27.4	75	1007.7
9	2021-11-24T14:18:18+05:30	522	9	18	29	27.7	72	1008.1
10	2021-11-24T14:18:19+05:30	512	9	18	29	27	69	1008.2
11	2021-11-24T14:18:21+05:30	512	8	17	27	27	67	1007.9
12	2021-11-24T14:18:23+05:30	514	8	18	29	27.1	65	1007.3
13	2021-11-24T14:18:24+05:30	517	8	18	30	27.3	66	1006.5
14	2021-11-24T14:18:25+05:30	519	8	18	30	29	66	1005.7
15	2021-11-24T14:18:27+05:30	519	10	19	32	27.6	64	1005
16	2021-11-24T14:18:28+05:30	520	9	18	29	27	63	1004.4
17	2021-11-24T14:18:30+05:30	524	8	17	29	27.7	67	1004.1
18	2021-11-24T14:18:31+05:30	526	8	17	29	27.5	67	1004.3
19	2021-11-24T14:18:33+05:30	528	8	17	29	27.8	71	1004.7
20	2021-11-24T14:18:34+05:30	528	9	18	30	27.9	74	1005.3
21	2021-11-24T14:18:36+05:30	529	9	18	30	28	74	1006.2

Hourly $PM_{2.5}$ levels recorded at Colombo and other urban areas are presented in Figure 7

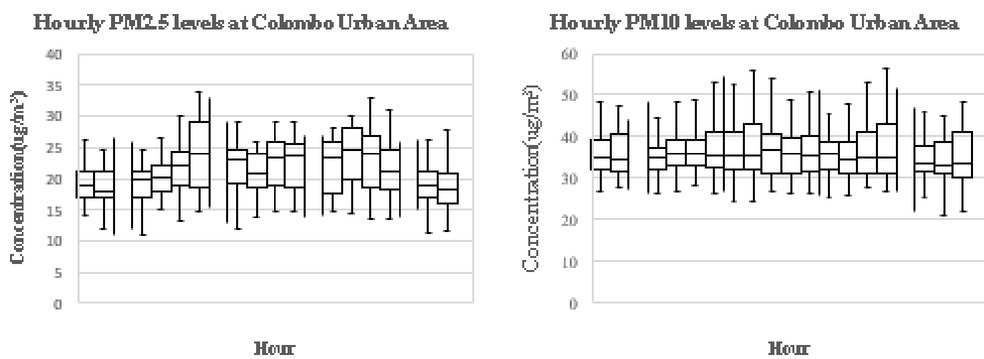


Figure 07: Box plot of hourly concentration of $PM_{2.5}$ and PM_{10} levels in Colombo urban area during weekdays

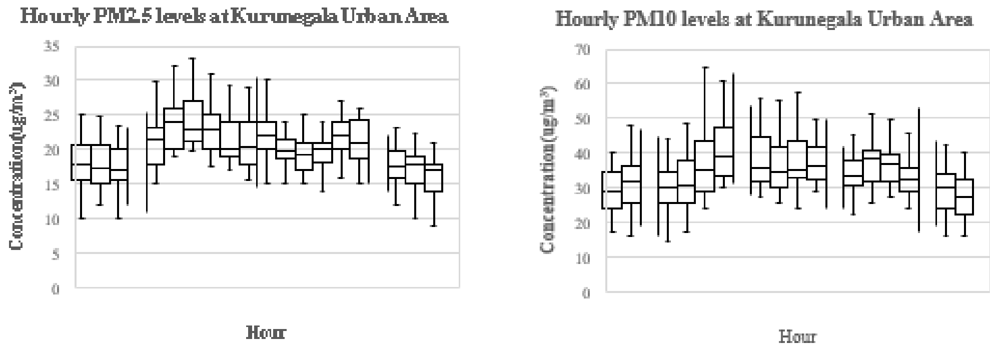


Figure 08: Box plot of hourly concentration of $PM_{2.5}$ and PM_{10} levels in Kurunegala urban area during weekdays

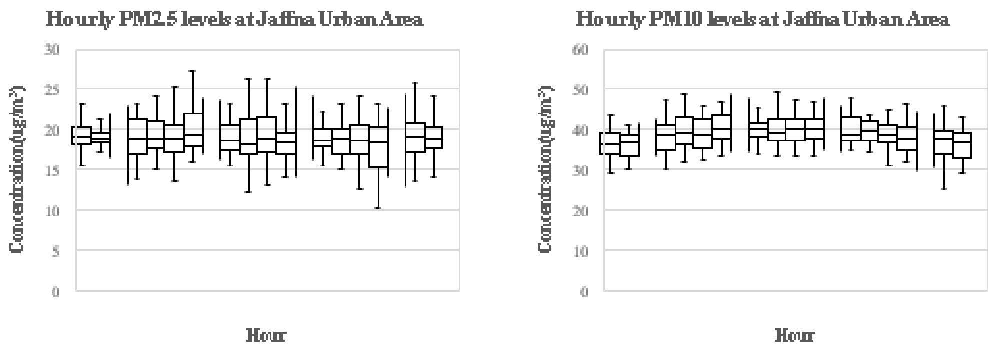


Figure 09: Box plot of hourly concentration of $PM_{2.5}$ and PM_{10} levels in Jaffna urban area during weekdays

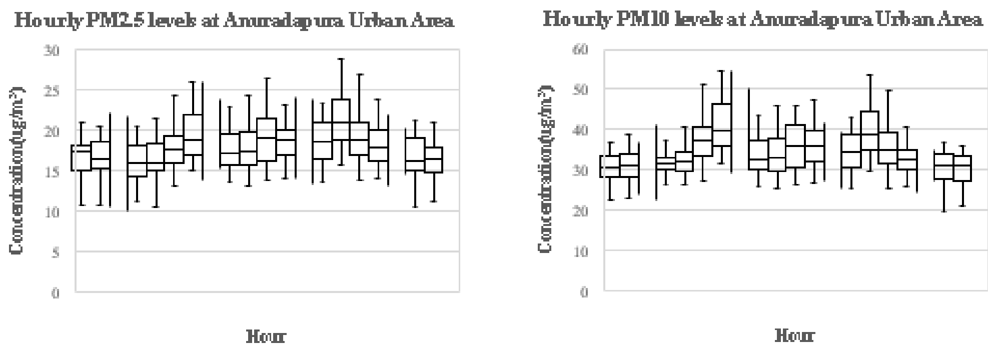


Figure 10: Box plot of hourly concentration of $PM_{2.5}$ and PM_{10} levels in Anuradhapura urban area during weekdays

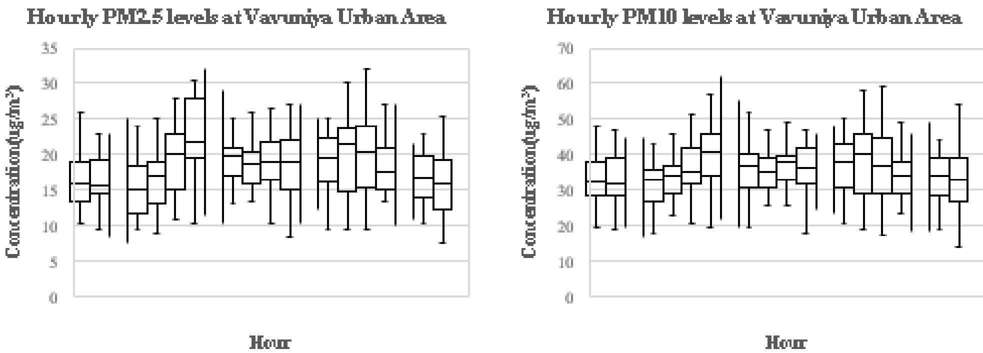


Figure 11: Box plot of hourly concentration of $PM_{2.5}$ and PM_{10} levels in Vavuniya urban area during weekdays

Accordingly, relatively high concentration of $PM_{2.5}$ levels were shown during 7:00 am to 9:00 am in morning, and 12:00 pm to 14:00 pm in afternoon and 17:00 pm to 20:00 pm afternoon representing peak traffic period in Colombo area. As shown in Figure 8, Figure 10 and Figure 11, the same situation was seen in Kurunegala, Anuradhapura and Vavuniya urban areas, respectively, as well. But no such pattern was observed in Jaffna urban area. In Jaffna, AQM unit was installed near the Jaffna - Palali Road which usually do not have high vehicular movements. Similar pattern can be observed for the variation of PM_{10} levels as well.

The daily variation of $PM_{2.5}$ and PM_{10} of Colombo are shown in Figure 12 and 13. Colombo monitoring site located in the Meteorology Department premises, which is immediately next to Bauddhaloka Mawatha with heavy traffic during office and school rush hours. Overall, in some days, 24 - hour average $PM_{2.5}$ levels are higher than the 24-hour standard value (50 µg/m^3) from January to February and then the levels drop from March to September. Similar pattern can be observed in PM^{10} levels as well but 24 - hour average levels do not exceed the 24 - hour standard value (100 µg/m^3) during the study period.

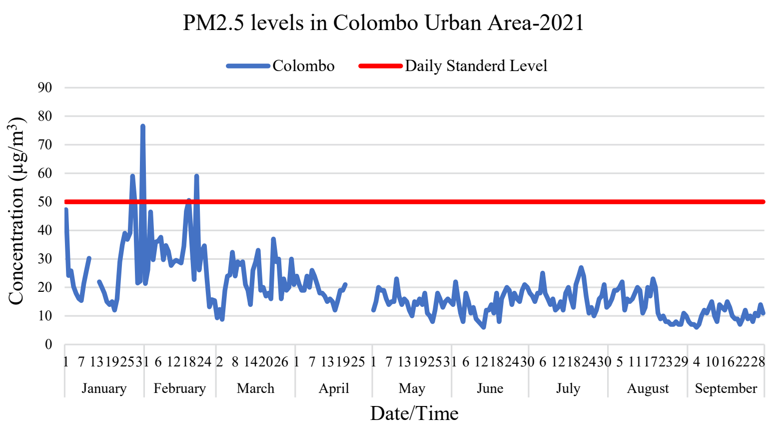


Figure 12: Daily concentration of $PM_{2.5}$ levels in Colombo urban area

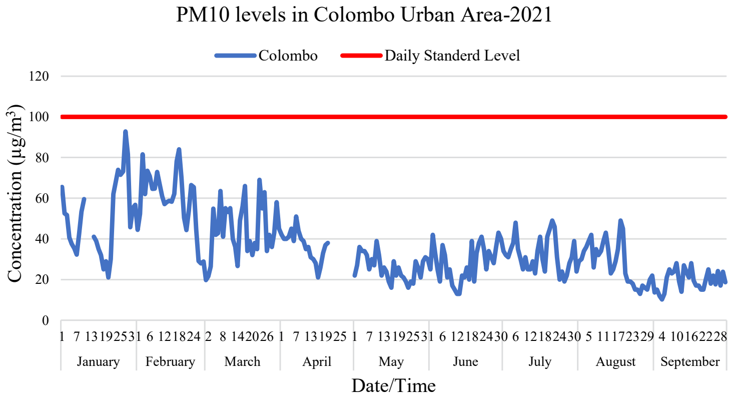


Figure 13: Daily concentration of PM_{10} levels in Colombo urban area

High levels of PM concentration from January to February could be attributed mainly to the transboundary air pollution. These seasonal fluctuations depend mainly on the monsoons weather patterns. Usually, transboundary air pollution reaches Sri Lanka with the Northeast monsoon from November to February. Also, the northeast monsoon from December to February is Governed by semi-permanent wintertime high pressure over the Himalayas. This forces cooler, stable air over Sri Lanka, retarding pollutant dispersion and resulting high PM levels during the period.

The first inter-monsoonal periods (March - April) and the South Western monsoon (May to September) brings rain and clean marine air to Colombo, resulting significant pollutant dispersion and washing. The low pollutant levels are further facilitated by the low vehicular activities due to COVID-19 pandemic travel restrictions.

Measured $PM_{2.5}$ and PM_{10} levels at other urban areas are summarised in Figure 14 and Figure 15, respectively. Overall, relatively high PM levels are recorded from January to February, however, these levels do not exceed 24-hour standard value in any of these urban areas. The air quality becomes better from March to September. Similar pattern can be observed in PM_{10} levels as well during the study period.

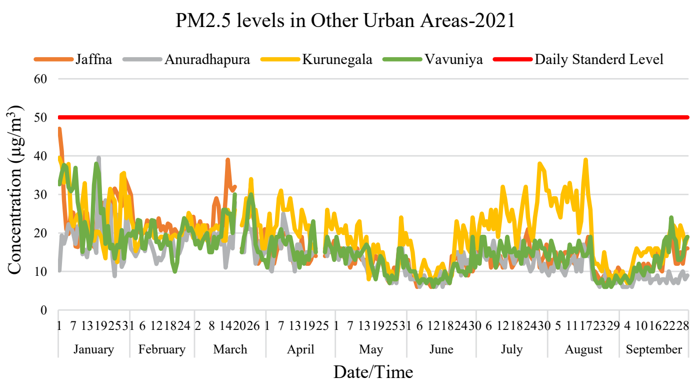


Figure 14: Daily concentration of $PM_{2.5}$ levels in other urban area.

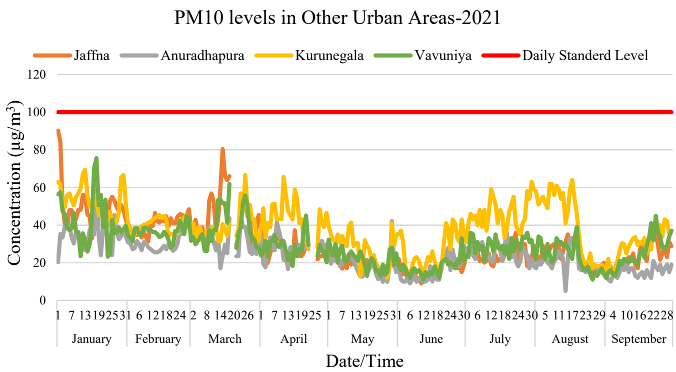


Figure 15: Daily concentration of PM_{10} levels in other urban area

High PM peaks observed in each urban areas from January to February is mainly due to the transboundary air pollution. Intensity of the peaks is mainly depended on the amount of pollution reach the urban areas with the wind pattern.

Kurunegala monitoring site is located along the Colombo - Anuradhapura road and near to a construction site, which may explain why the PM concentration is higher compared to other urban areas. Further, midday concentrations do not drop as much as other sites even during the COVID-19 lockdown period.

The Jaffna site is located 1km away from the main Jaffna - Palali road and very close to the agricultural field. However, the agricultural operation of the field impacts at the PM monitor and PM level shows a subtle increase during the period of farming in the nearby field.

Anuradhapura and Vavuniya monitoring sites located in sub urban areas near to the main roads. Therefore, PM levels are increase in these urban areas with the growth of traffic conditions.

4. Conclusion and Recommendation

A real-time AQM sensor system has proven to be a useful instrument to study hourly variability of PM concentrations in urban and other areas in Sri Lanka. It gives location - specific characteristics of PM data that cannot be achieved with a single or multiple High - volume stationary monitoring units.

The main cause of urban air pollution is the high vehicular traffic congestion. It has been observed that PM concentrations were increased in urban areas with increasing traffic intensity. Analysis of the temporal variability demonstrated that the highest PM concentrations were observed during the morning hours (7:00 am-9:00 am) and during the (12:00 pm-14:00 pm) afternoon and evening (17:00 pm-20:00 pm) in the week days. During these time periods, high traffic congestion can be observed in roads. During Saturday and Sunday, less traffic in urban areas and PM levels decreased.

During the last few months of the year, transboundary pollutions from reached Sri Lanka due to the prevailed wind pattern. Those high concentrations of pollutants were heavily impact to the increasing of local air pollution levels.

4. References

1. Nguyen Cong Thanh, L. H. (2019). A Choice Experiment to Estimate Willingness-To-Pay for Air Quality Improvements in Hanoi City: Results of a Pilot Study. 10th Neu-Kku International Conference Socio-Economic And Environmental (p. 1112). Vietnam: Social Publishing House.
2. Priyankara, S., Senarathna, M., Jayarathna, R. (2021). Ambient PM2.5 and PM10 Exposure and Respiratory Disease Hospitalization in Kandy, Sri Lanka. Environmental Research and Public Health, 18.
3. WHO. (2016, September 27). WHO releases country estimates on air pollution exposure and health impact. Retrieved from World Health Organization: https://www.who.int/news/item/27-09-2016-who-releases-country-estimates-on-air-pollution-exposure-and-health-impact
4. Withanage, H. (2019, June 05). Press Release for World Environment Day: Air Pollution is a silent killer in Sri Lanka. Retrieved from Friends of the Earth Asia Pacific: https://foeasiapacific.org/2019/06/05/press-release-for-world-environment-day-air-pollution-is-a-silent-killer-in-sri-lanka/

INNOVATION GEAREC
Building Resilience

Design and Implementation of Data Warehouse to Facilitate the Landslide Risk Management Process

S Jayaprakash[1], SDA Jeevana[1]

[1] Scientist, National Building Research Organisation, Sri Lanka

Abstract

The era of data warehouse has certainly brought up new possibilities for the management of natural disasters, mainly because of its wide range of options for visualizing, evaluating and predicting natural disasters. Data warehouse has significantly altered the ways in which human societies implement natural disaster management tactics to lessen human suffering and economic losses from this perspective. In a society that is more reliant on information technology, computer professionals and policy makers are working to make use of most of the data by sourcing in a variety of formats and storing it in ways that can be used successfully during various stages of natural disaster response. So, the aim of this paper is to create a systematic data warehouse which can support and facilitate the decision-making process on effective landslide risk management by storing, managing, standardizing, analyzing, and sharing data collected from a variety of sources, including manual questionnaire surveys, spatial surveys via digital apps and census and statistic information from secondary sources

Keywords: data warehouse, disaster management, element at risk

1. Introduction

Heavy loss of life as well as unprecedented damage to property and infrastructure caused by landslides in recent decades prompted the relevant institutions to initiate appropriate measures for the reduction of impacts of landslides (Celik & Corbacioglu, 2010). As an initial step, comprehensive landslide risk assessment process has been incorporated as a crucial part of an integrated risk management process where critical decisions must be made (Sutanta, Bishop, & Rajabifard, 2010).

A key step in quantitative landslide risk assessment is the identification of the "elements at risk" and the estimation of the outcome or "consequence" of the landslide event on these elements. Outcome of landslide risk profile presents foundation for devising long-term sustainable risk reduction strategies to address adverse exposure conditions that contribute to susceptible landslides. Estimation of the consequence requires proper transformation of raw data which were collected through the identification of elements at risk step into insightful information.

Considering the impacts caused by landslide hazard, in 1986 the Cabinet of Ministers of the Sri Lankan Government decided to launch Landslide Hazard Zonation Mapping Project to identify the distribution of landslide potential in the central high lands. This project is being implemented in 14 landslide prone districts namely; Badulla, Nuwara Eliya, Kandy, Matale, Ratnapura, Kegalle, Kalutara, Galle, Matara, Hambantota, Colombo, Gampaha, Kurunegala and Monaragala.

The landslide hazard zonation map is a map of an area delineated with different probabilities to initiate landslide. The main objective of this mapping exercise is to identify the identification of areas vulnerable to landslide hazard and followed by the establishment of good engineering practices in planning and construction, creation of public awareness, introduction of guidelines to ensure proper construction procedures and the ultimate aim being the mitigation of landslide hazard. Landslide hazard maps are used as a planning tool. Thus, the maps are utilized in planning of settlements, infrastructure and development activities in hilly areas of Sri Lanka. These maps are also utilized for policy & decision making, in the selection of suitable lands for relocating communities living in highly vulnerable areas, for identification of mitigation measures and in the issuance of landslide early warning.

Based on hazard zonation maps, landslide risk profile development project was initiated to gather data in detail on elements in high hazard zones. Preparation of landslide risk profiles are essential for enabling the National and Sub - National level agencies to assessing disaster risk and making decisions for short-, medium and long-term disaster management for disaster prone areas. Adhering to this outcome, risk profiles have been developed to enhance the capacity of National and Sub - National level agencies in assessing the disaster risk and formulating short-, medium- and long-term disaster risk reduction decisions.

Purpose of the said project is to identify buildings exposed to landslide hazard and to gather information on; (i) demographic profile (ii) land use and characteristics of the buildings (iii) construction guidelines followed in construction (iv) impacts caused by disasters (v) availability of disaster preparedness measures and (vi) disaster risk reduction measures. Landslide risk profile also can be used as a decision-making tool in development planning and to establish landslide early warning system.

The scope of the project is as follows:

A. Development of landslide risk profiles for Divisional Secretariat and Local authority levels;
   - Systematic description of the characteristics of the inhabitants, characteristics and use of the buildings, disaster impacts, disaster preparedness and disaster risk reduction measures executed by inhabitants

B. Inventory of exposures of the following elements at risk;
   - Housing units in terms of number of families, gender, age, livelihood etc.
   - Commercial/institutions, school, religious units in terms of their structure type and functionality, infrastructure, disaster preparedness etc

C. Develop a spatial database (attribute data referred with geographical coordinates) of communities at risk, will be incorporated into development planning process.
   - Prioritization of communities in terms of different landslide hazard zones with population, housing, land use, livelihoods, critical facilities, infrastructure and relevant DRR and response options

In order to store, manage, standardize, analyse and share the elements at risk data which is collected through various sources such a manual questionnaire surveys, spatial survey through digital apps, and the census and statistic information from secondary sources, there is a need for the development of proper data warehouse which can support and facilitate the decision-making process on effective landslide risk management (Villars, Olofson & Eastwood, 2011).

2. Literature Review

There are numerous research works conducted on the utilization of data warehouse for disaster management purposes. Especially the research journal on the topic of "Warehouse data integration system for natural disaster management", (Ijadin & Adriana, 2015) has proposed a dataware house design for developing a flexible, scalable, highly portable and self-supporting centralized network and modular component facility to assist the corresponding approach and detail supervision and quick response to disastrous situations which can be originated from natural and manmade incidents.

The objective of this research was to identify the method to create a coordinated communication system to respond and facilitate the emergency operations. Further data integration was identified as a key issue in this domain since required data were found in different sources, thus there was a need to integrate data from all the available sources and transform into actionable format and finally use it for disaster coordination activities. This data warehouse can be utilized in all four stages of disaster management cycle i.e., Prevention and mitigation, Preparedness, Response and Recovery and rehabilitation. It applies Inmon approach of designing a Data warehouse as described in the Figure 1.

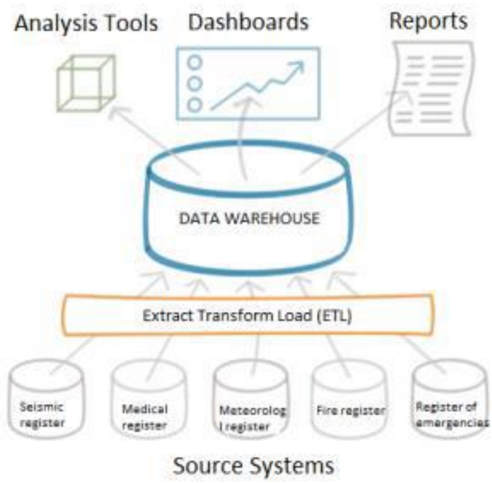


Figure 01: Inmon approach of designing a Data warehouse (Source: (ijadin & Adriana , 2015

ETL process was implemented to retrieve the data from multiple sources such as seismic, medical, meteorology, fire and emergency departments, then reformat and cleanse them, and finally load them into the data warehouse for analysis. By implementing a data warehouse, it was able to eliminate data redundancy and inconsistency by achieving the paperless sharing of data and increasing the confidence in data quality. Further data warehouse enhances the efficiency of operational responsibilities.

Assilzadeh and Mansor (2016) developed a methodology called Hazard Decision Support System (HDSS). It refers to the plan that must be established to meet the needs of pre-disaster, disaster, and post-disaster operations. This company? must make use of the most up-to-date communication and information technology to provide users with an online system that may be accessed by a private network, Internet connectivity, or data radio communication infrastructures. Users can use devices such as mobile data terminals to send and receive information as needed in fulfilling their individual activities and obligations, depending on how handy it is during operation, particularly during disasters. Even SMS can be used to send urgent information to mobile phones.

Decision Support System (DSS), Reporting Wizard (RW), and Data Management System (DMS) are among the primary features and functionalities of HDSS that allow administrative and operational duties to be carried out more efficiently and cost effectively. The HDSS organization is made up of application modules that cater to all disaster-related needs. The organization of this hazard management system is depicted in Figure 2.

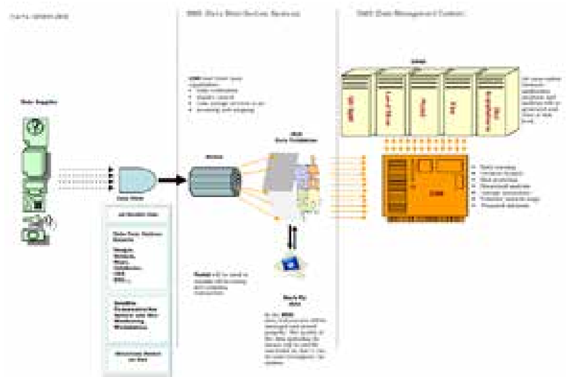


Figure 02: Natural Disaster Data and Information Management System configuration

Also, Serpil, G (2018) developed a same kind of methodology by using GIS technology which can be used before, during and after a disaster, in an emergency, or in a crisis.

3. Methodology

The process followed to develop the landslide risk profile is primarily divided into three main stages as:

3.1 GN Division level landslide hazard zonation mapping

3.2 Elements at risk analysis and

3.3 Generation of spatial data base on elements at risk

The necessity of establishing the data warehouse arises in second and third steps, especially to convert the elements at risk data collected through various sources to analysable format and accommodate all the relevant information in a single source which can be distributed among the relevant stakeholders. The role of data warehouse in landslide risk assessment process can be understood by referring the aforementioned steps.

Elements at risk analysis

The characterization of consequence scenarios is based on elements at risk and vulnerability of elements at risk. Analysis of elements at risk can provide background data as a guide to the decision-maker. Main Elements at risk are the population, properties, economic activities, or any other defined values exposed to hazards in a given area. The aim of elements at risk analysis is to assess the characteristics of the inhabitants, characteristics and use of the buildings of the elements at risk for landslides. Buildings are one of the main groups of elements at risk in a hazardous event. It comprises the inhabitants and the properties accommodated in the buildings.

Findings from the elements at risk analysis depicts characteristics of the inhabitants, potential consequences of the landslide events, structural condition of the buildings, status of rain water management, knowledge about landslides, disaster preparedness information, preferences in the event of landslide induced relocation etc. Methodology employed for elements at risk analysis has been represented as a flow chart.

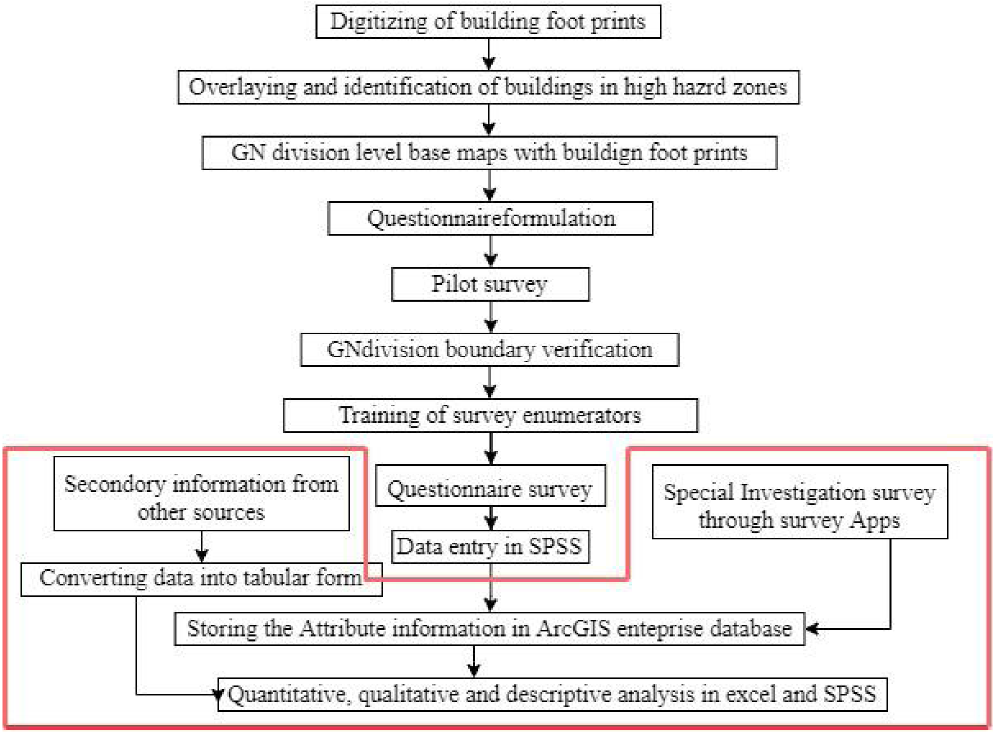


Figure 03: Methodology employed for elements at risk analysis

As the first step, communities who are located on high hazard zones were selected as the target group for the survey. The survey was done using four questionnaires which are for Households, Commercial establishments and Institutions, Schools and Religious places at Grama Niladhari Division level.

Reference maps were prepared using ArcGIS desktop version and Google Earth Pro. The maps were distributed among Grama Niladharies while providing training for familiarization with the maps. Each building unit has a unique number to identify its geographical location and same number was provided to filled questionnaire. It helps to create spatial joining of attributes in preparing of database.

Further, investigation of reported landslide related incidents and they are named as landslide special investigations (LI). A simple questionnaire was prepared to collect the data by using "Survey 123" which helps to create and deploy custom mobile apps. Survey 123 collects the data into a spreadsheet format that store data in the cloud storage. The app and spreadsheet stay synchronously in sync via cloud storage service. After collection of the field data, they are converted into vector format using ArcGIS Desktop Software.

Generation of Database on Elements at Risk

Generation of database is the final stage of the landslide risk profile development. A database is an organized collection of records and can be called as a type of electronic filing system that enables efficient and quick retrieval of data. Purpose of generation of data base is to visualize the characteristics of the vulnerable communities among the stakeholders for decision making purpose. which offer opportunity of maintaining both statistical information combined with geospatial data.

Database on elements at risk should contain information on; (i) demographic profile of the households (ii) land use and characteristics of the buildings (iii) construction guidelines followed in construction (iv) impacts caused by disasters (v) availability of disaster preparedness measures (vi) disaster risk reduction measures practiced by the occupants.

So far, questionnaire survey on over 100,000 households has been conducted which spreads in 10 Districts, and it is estimated that the survey will continue on another 600,000 households. Further, a considerable amount of Special investigation incidents is reported, and such information is collected through digital survey apps. However, for this particular research only portion of the household information surveyed for Kalutara District has been considered.

Data warehouse design

In order to establish a data warehouse to facilitate the effective landslide risk assessment system, this paper follows Immon's Top - Down Approach for designing a data warehouse. It adopts traditional relational database tool to facilitate decision - making process (ZIJADIN, 2015). This approach points out three main considerations. The first is data normalization and definition of Meta data modelling for both data and process modelling like typical database modelling system, the second is support to end users' decisions through subjective queries to the database, and the third is data cleaning and amalgamation in the data preparation stage which is referred as staging area for transforming the operational and other data sources into insightful information. Following image shows pictorial representation of the design.

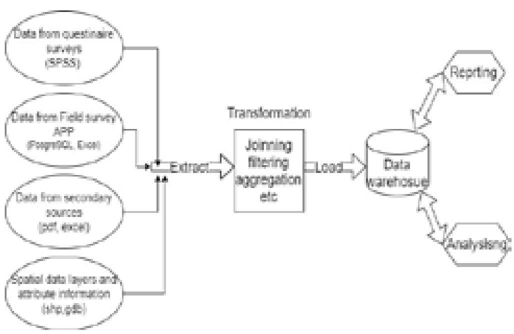


Figure 04: pictorial representation of the proposed data warehouse design

This top-down approach is implemented through unique nine step methodology, which starts with the understanding the scope of the context.

Step 1 : Determining the requirements based on the main objectives of the context is a preliminary step of this design, since the data warehouse is for facilitating the landslide disaster risk management decision-making process, it focuses on analysing and estimating the risk based on three main sources such as root cause, dynamic pressures and unsafe conditions exist in the households which are located in the landslide prone areas of Kalutara District.

Step 2 : The second step focuses on identification of the granularity, which determine the level of information that can be obtained from the data warehouse, since the process is oriented towards identifying risk measures information from surveyed household units, it focuses on GN Divisional level as the depth of information

Step 3 : Based on the purpose, descriptive information which declares the dimensions presented in the main fact of this process is identified, and the following table shows the key dimensions of this data warehouse.

Table 01: Description of dimension table

Dimension Name	Description
Dim Root Cause	It includes information related to impact of natural disasters and householders' preferences to live in the disaster-prone area
Dim Dynamic pressure	Information focusing on physical properties of the house construction and strategies used for the construction process
Dim Unsafe Conditions	Information of intangible vulnerability factors exist in the household especially economic condition
Dim Date	Information about construction of the houses, particularly year of construction, and within specific range years
Dim Location	Locational information of the house including coordinates, and administrative boundaries

Step 4: - Landslide risk is selected as the main fact of this data warehouse. There are number of other fact information also available such as, vulnerability, exposure and hazard. However, other facts are representing small portion of this process, thus fact risk is a best representative fact which can provide meaningful information.

Step 5: - Number of precalculated values such as vulnerability level, exposure level and the coping capacity are included in the fact risk measures, which are representing the calculated values from the numerical attributes of the key dimensions

Step 6: - Key dimensional attributes to explain the measures presented in the fact table is identified in this step.

Table 02: Attributes of dimension

Dimension Name	Attributes
Dim Root Cause	(i) Disaster affect, (ii) Land susceptible disaster, (iii)Damage road (iv)Relocation preference area (v) Relocation house preference
Dim Dynamic pressure	(i) Professional support (ii) House design (iii) Materials foundation (iv)Type wall (v) Connection roof structure (vi)Terrain type (vii) Engage in disaster management activities (viii) Precautions landslide (ix)Instruction disaster preparedness
Dim Unsafe Conditions	(i) Membership society (ii) Occupation
Dim Date	(i) Year Construction
Dim Location	(i) District (ii) DSD (iii) GND (iv)Local authority

Step 7: - Determining the time period on how long the database shall store the information. It is expected to complete the landslide hazard zonation maps for entire country within another 7 years, then further surveys will be carried out for another 5 years, thus it is expected keep the data for another 12 years

Step 8: - Information comes from questionnaire survey is static, even the aforementioned attributes change over the time, not all the information is changed, however through the continuous digital surveys, attributes in the root cause dimension shall change over the time.

Proposed design

Figure 05: Proposed design-based on star schema

In order to facilitate the analysis of landslide risk related information, star schema-based dimension modelling is proposed after considering the simplicity of the data warehouse design and to enhance the better query performance. Star schema consists with a fact table and number of dimension tables. Fact table contains the foreign keys (here surrogate keys are used) of available dimensions measures.

Extract, transfer, load (ETL) solution

Extract-Transform-Loading process is a significant component in data warehouse. Since the data come from multiple heterogeneous sources there is a necessity to integrate those? these? data into an analysable format and load into the warehouse, which can support key requirements of the business process. (Gour, Sarangdevot, Tanwar, & Sharma, 2010).

First step in ETL process involves extracting the data from all identified sources, and with regard to this particular process, tabular data comes from questionnaire surveys, via digital apps, spatial databases and other secondary sources. Then transformation stage applies set of rules and functions such as filtering, joining, sorting, aggregating etc to clean, reformat, insert, customize and integrate the data. Therefore, this is considered to be the crucial and time-consuming task in the development of data warehouse.

ETL process was done in three platforms, first and foremost, to convert the data comes from spatial data layers such as administrative boundaries and digital survey apps, spatial ETL tool under data interoperability extension of ArcGIS software was used, these Spatial ETL tools are user-created geoprocessing tools that can transform data between different data models and different file formats. It can be created with FME Workbench in a translation work space and save them in a toolbox. Further spatial ETL tool are used for following purposes

- Filtering attributes and merging them with other feature classes
- Using attribute values to create unique feature classes on the fly
- Separating data using test criteria

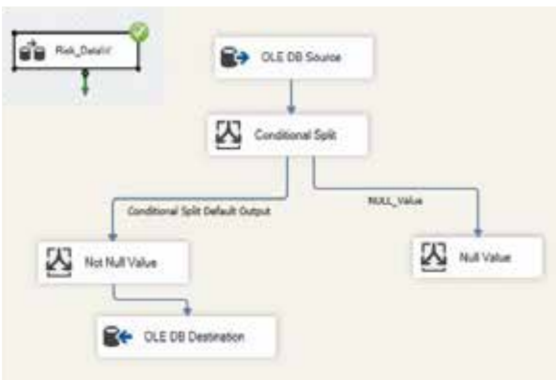


Figure 06: Removal of null values using SSIS

Secondly, pivot tools in the Excel were used for number transformation of the questionnaire data comes from the SPSS, particularly calculated measures with numerical values from existing dimensions which represent the weight values of social vulnerability, root causes and dynamic pressures were derived.

In order to eliminate the null data and missing values in the data set Microsoft SQL Server Integration Services (SSIS) with necessary components were used. In this process data was standardized in an analysable format further require data was derived through the aforementioned transformation rules and functions.

4. Analysis

Based on the proposed data warehouse developed on star schema-based dimension model, various analyses towards identifying the landslide risk are performed. The main dimensions such as root causes, dynamic pressures and unsafe conditions were used to determine the vulnerability, exposure and risk level of the households in terms of GN level, DSD level and District level hierarchies. Importantly landslide Risk Index for GN level is calculated by calculated measures in the fact table which consist of key dimensions such as underlying causes, dynamic pressures and un-safe conditions. Below equation was applied to the calculated measure of risk value.

Risk value = N. Log A x Log B x Log

$$A = \frac{D2+D_3+D4}{\mathrm{R1+R2}},\ B = \frac{1}{\sum_{e=1}^{12} Hi+T1+T2+T3+T4+T5},\ C = \frac{1}{\mathrm{E1+O1}}$$

Root causes	dynamic pressures	Un-safe conditions
D2 = House affected by disaster	H1 = Professional support obtained to build house	E1 = Employment
D3 = House/land susceptible for disaster	H2 = Designer of the house	O1 = Membership in a village level society/ organization
D4 = Access Road to your house affect by disaster	H3 = Approval obtained for house construction	
R1 = In the event of disaster induced relocation, where do you prefer to relocate	H4 = Materials use for foundation of the house	
R2 = In the event of disaster induced relocation, type of housing for in relocation	H5 = Materials use for wall construction of the house	
	H6 = Type of wall	
	H7 = Materials use for Floor	
	H8 = Roofing materials	
	H9 = Connection between House structure & Roof structure	
	T2 = Engage in Disaster Management activities	
	T3 = Take any precautionary measures to face landslide during last three years	
	T4 = Availability of disaster management committee in the village	
	T5 = Receive instructions on disaster preparedness	

Further based on the coordinate information and other properties, it is possible to show the spatial pattern of the various properties which included in the fact table. Following are example of results of some of the analyses done in power BI.

The line graph of the construction year of households in landslide prone area reveals, there is an increase in the construction of houses during the period of 2000-2010, from this we identify the average age of the buildings, which gives one of the essential information on strength and land use change, and help in identify the vulnerability of the physical structure.

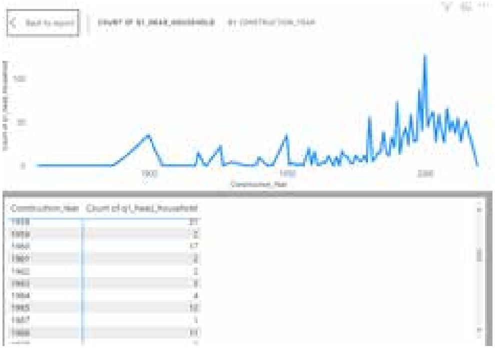


Figure 07: House hold units by year of construction

Figure 08: Spatial distribution of the houses by Terrain type

Identifying the spatial pattern helps to correlate the household properties with landslide hazard zones, which gives crucial idea on how the location of the houses can expose to risk, by combining the location, and construction year and other properties, it is possible to predict the trend of settlement development, based on those trends, decision - makers can take preventive measures or control the construction of houses in high hazard area.

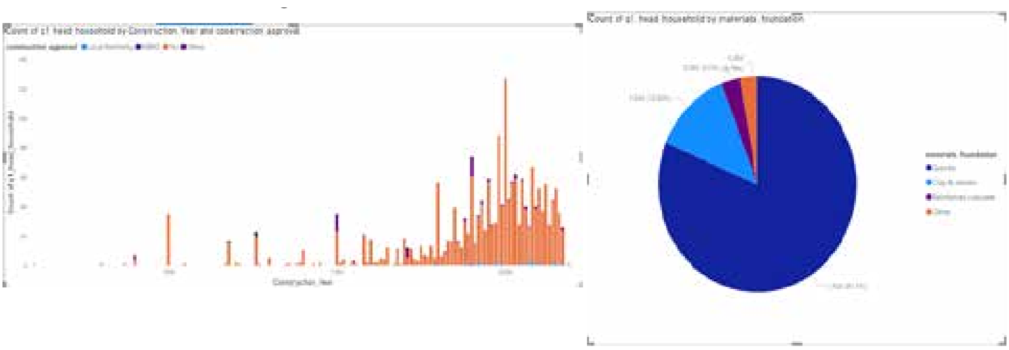


Figure 09: Time series pattern of house construction with construction approval pattern

Obtaining the approval from relevant agencies ensure that the houses are constructed according to the prior approval and clearance, since this clearance system assess suitability of land for construction, this data is valuable in assessing how many houses got prior approval. Based on the above chart it is revealed that only few houses have obtained the approval over the time span.

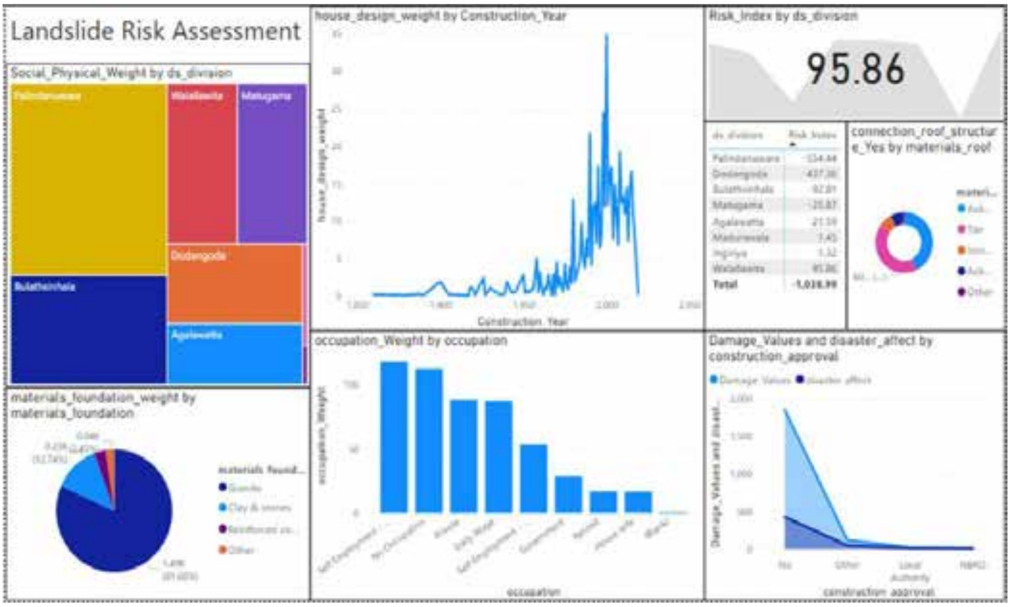


Figure 10: Dash board created for the visualization purpose based on the implemented

5. Conclusion

Developing a proper data warehouse for the Disaster Risk Management plays crucial role in all the aspect of Disaster Management process. Specially preparedness, response, recovery and mitigation activities can be well planned, as a result risk caused by the landslide disaster can be reduced to considerable extent.

The proposed data warehouse for the landslide risk assessment process reveals importance of having a proper analytical system with well-designed data warehouse. It has the ability to facilitate the analysis in terms of various dimensions. Form the aforementioned analysis, it can be identified, that a risk for the households located in the landslide prone areas can be evaluated in terms of root causes, dynamic pressures and unsafe conditions which were derived through various data collection sources.

Base data related to natural hazards such as landslide, floods and information on elements at risk components such as household units, commercial units, administrative establishments, schools and other social infrastructure facilities comes from various sources. Often the data comes with different formats as they are gathered by various institutions, but those data contain essential information which can be utilized for disaster management purposes, if there is proper data warehouse structure is implemented.

Proposed data warehouse focuses on the risk assessment aspect only, however there are number of further activities such as mitigation (both structural and non-structural) are carried out by relevant disaster management institutions. There are number of databases developed to facilitate the resettlement and awareness activities taken places in the identified landslide risk areas, thus incorporating such data can further improve the risk management as a whole process. In addition to that there are numerous automated rain gauges installed over the Country, which produce rainfall measurements at every 30 minutes, since rainfall is a triggering factor of the landslide, accommodating time series rainfall data will improve the risk identification in terms of temporal aspect.

6. References

1. Celik, S., & Corbacioglu, S. (2010). . Role of information in collective action in dynamic disaster environments. Disasters. (34), 137-154.
2. (2017). Environmental Guideline on Demolition of buildings. Republic of Mauritius.
3. Forensic, R. (2017, 08 15). Deep Excavation and Vibratory Damage. Structural Damage from Adjacent Construction Projects.
4. Gour, V., Sarangdevot, S., Tanwar, G., & Sharma, A. (2010). Improve Performance of Extract, Transform and Load Improve Performance of Extract, Transform and Load. International Journal on Computer Science and Engineering, 786-789 .
5. (2016). Guidelines on Preconstruction Survey. Singapore: Building and Construction Authority.
6. Jadin, K., & Adriana, G. (2015). Warehouse data integration system for natural disaster management. International Journal on ICT Education, Knowledge Society & Open Governance ICTEA Dubrovnik.
7. Kimball, R., & Ross, M. (2016). Fact Table Core Concepts in The Kimball Group Reader: Relentlessly.
8. Marseh, B. P., Heidarpour, B., Hosseinnezhad, A., & Soumehsaraei, B. G. (2013). Effects of Adjacent Building Construction: A Case Study. Journal of Basic and Applied, 370-375.
9. Musir, A. A., & Ghani, A. N. (2014). A study of pile driving effects on nearby building. International Journal of GEOMATE, 806-810.
10. Rahutomo,, R., & Pardamean, B. (2018). Building Datawarehouse for Educational Institutions. 2018 Indonesian Association for Pattern Recognition International Conference.
11. Smith, N., Vatovec, M., & Gumpertz, S. (2015). Mitigating and Remediating Damage to Properties Adjacent to Construction in Congested Urban Environments. ICRI Spring Convention.
12. Sutanta, H., Bishop, I., & Rajabifard, A. (2010). Integrating spatial planning and disaster risk reduction at the local level in the context of spatially enabled government. n Spatially Enabling Society Research, Emerging Trends and Critical Assessment, 55-68.
13. Villars, R., Olofson, C., & Eastwood, M. (2011). Big Data: What It Is and Why You Should Care. USA: IDC: Framingham, MA.
14. ZIJADIN, K. (2015). The Role of Data Warehouse during the Natural Disaster. EUROPEAN ACADEMIC.

National Building Research Organisation

11th Annual Research

Symposium 2021

INNOVATION GEARED

BUILDING RESILIENCE

Technical Session 4

Non - Structural Measures for Landslide Risk Reduction

Preliminary Study for Application of X-band Dual Polarization Weather Radar System in Sri Lanka

T Hirose[1], S Mitsunaga[1], A Toda1, T Koike[2], T Wada[2], H Sakamoto[2]

[1]FURUNO Electric Co., Ltd., [2]Earth System Science Co., Ltd.

Abstract

National Building Research Organisation (NBRO) is the responsible agency to provide landslide early warning in Sri Lanka. The warning is issued based on land observation data of limited number of rain gauges, and it is difficult to grasp the 2-dementional rainfall distribution especially in steep mountain area. A preliminary study was carried out for application of X-band dual polarization weather radar system, which can improve local rainfall observation with low initial cost in Sri Lanka. In this study, we also verified the necessity of complementary operation with C-band weather radars which will be installed by Department of Meteorology under the support of Japan International Cooperation Agency (JICA). Consequently it was concluded that both radar systems can interpolate each other according to the characteristics and the target area.

Keywords: ***X-band radar, Dual polarization, Rainfall observation, Early warning, SDG's business***

1. Introduction

Landslides are one of the most serious natural disasters in Sri Lanka. The central mountainous region counts for 20% of the total land area and 30% of the population of Sri Lanka. Due to the natural conditions such as fragile geology and steep terrain in addition to the recent rapid reclamation and urban development, the landslides including slope failures and debris flows frequently affect to the human lives especially in monsoon season.

In order to reduce the landslide risks in the mountainous region, it is an urgent need to build a system for information collection, accumulation and analysis quickly and accurately delivering it to the decision makers to response landslide disasters.

Furthermore, it is highly required to detect high-quality rainfall data, especially localized heavy rainfall in mountainous regions. NBRO has been issued landslide waning system based on their dedicated rainfall monitoring, and the information has been shared with relevant parties such as Disaster Management Centre and Department of Meteorology. However, those rainfall data are captured only by limited number of land rain gauges, and it is difficult to grasp the 2-dementional distribution of the rainfall and generation, development and movement of the rain clouds. From this point of view, we propose to install X-band dual polarization weather radar system in Sri Lanka, and provide high density and high quality rainfall information in collaboration with NBRO.

2. Outline of X-band dual polarization weather radar

FURUNO Electric Co., Ltd. has been providing fish-finders and marine radars, which boast the world's top share. By using the know-how cultivated in such business, "Portable X-band dual polarization weather radar" was developed in 2013. Realising miniaturization and high resolution, the weather radar can accurately and early detect local heavy rainfall, which has been difficult to detect in the past.

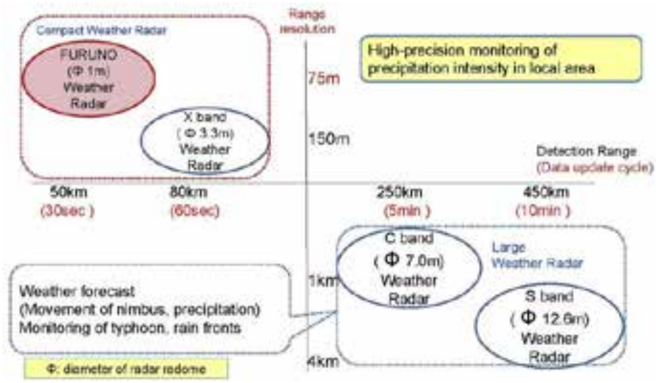
Figure 01: X-band dual polarization weather radar carried by a vehicle

Unlike conventional weather radar, it is small and light weight, so there is no need to invest in ad dedicated building or tower. It can be installed in existing buildings by human power. It can be loaded on general vehicles and use as portable radar. In terms of functionality, it is possible to observe rainfall from 500 m above the ground with resolution of 100 m. In addition, by using dual polarization technology, it is possible to capture the grain size distribution of raindrops, and the accuracy of rainfall calculation is dramatically improved compared to the conventional single polarization weather radars. It is also equipped with "Scenario Scan Function" that allow to customize the observation such as specifying radar rotation method and elevation angle, according to the observation target and user needs. Because of the low initial cost, the X-band dual polarization weather radar is suitable for introduction to private companies and development countries, and has been installed in Indonesia and Croatia though Japan International Cooperation Agency (JICA).

3. Proposed complementary operation of C-band and X-band weather radars

JICA is also preparing a grant project "Project for the Establishment of a Doppler

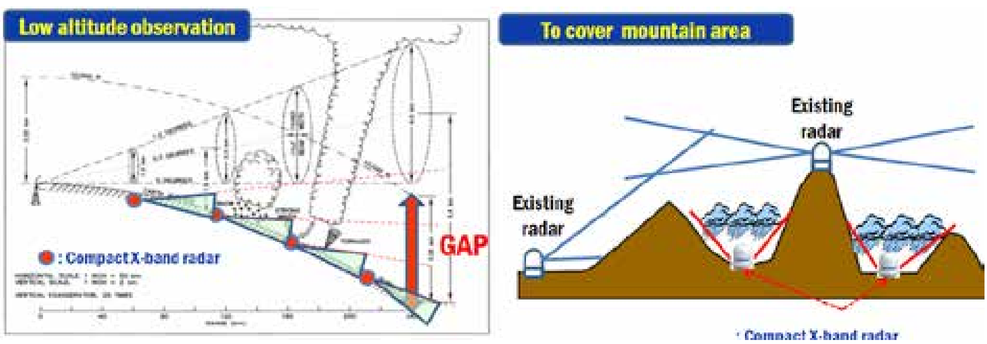
Weather Radar Network" to strengthen the capacity for real-time rainfall observation of Department of Meteorology. 2 sets of C-band weather radar will be installed in the western and eastern coast area, covering entire island of Sri Lanka. The proposed X-band radar can capture the local rain cloud development with high resolution, but in order to predict rain cloud movement in wide area, C-band radar is also very important. By complementary operation using both C-band and X-band radar system, NBRO becomes able to issue high accuracy landslide early warning effectively.



Source: FURUNO Electric Co., Ltd.

Figure 02: Relation of resolution and detection range of several bands of weather radar

An issue of wide range C-band weather radar is effective observation height. The radio waves are generally traveling straight with some refraction due to atmosphere. Since the earth surface is curved, the practical observation altitude is several thousand meters from the ground. Furthermore, due to interruption by terrain ranges, the observable altitude will further rise further.



Source: FURUNO Electric Co., Ltd.

Figure 03: Schematic Image of observable altitude of weather radar

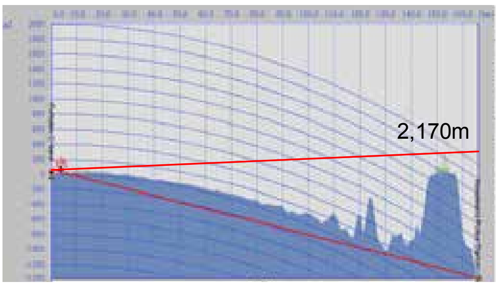
We verified the effectiveness of complementary operation of C-band and X-band radars in Ratnapura areas, where more than 100 landslides occurred due to heavy rainfall in 2017.

The C-band weather radars are planned to be install at Puttalam in the western coast and Pottuvil in the eastern coast (JICA, 2016). The location of the radar installation sites are given in Figure 4. Figure 5 shows cross-sectional views between the installation sites

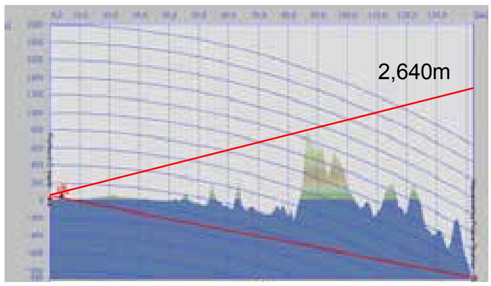
Figure 04: Planned location of C-band Doppler weather radar stations by JICA
Source: FRUNO

and Ratnapura area, taking into account the curvature of the earth's surface and the refraction of radio waves by the standard atmosphere. These represent the line-of-sight relationship when actually observed by C-band radar. Since there is a terrain range between them, a part of radio waves are blocked. The lowest altitude observable from Puttalam is approximately 2,170 m above ground at Ratnapura, and from Pottuvil approximately 2,640 m.

In general, rain clouds are formed from an altitude of about 500m, and grown up toward higher altitude causing local storms. Therefore, in order to detect meteorological phenomenon early with high accuracy, it is effective to add a small X-band radar to supplement the wider phenomenon captured by C-band radar. The planned C-band radars have antenna directing angle (beam width) of about 1 degree, whereas the proposed X-band radar is about 2.7 degrees, which is inferior in horizontal resolution. The X-band radar should be installed near the observation target area in the mountain, so that both radars effectively and complementary work together. In future, it will be necessary to develop integrated processing of the both radars considering their unique characteristics.



Puttalam to Ratnapura



Pottuvil to Ratnapura

Source: FURUNO Electric Co., Ltd. (topographical cross-section generated from SRTM)

Figure 05: Cross-sectional views between C-band radar installation sites and Ratnapura

4.Conclusion

Recently the X-band weather radar becomes popular in the world in addition to existing wide-range weather radar system. Because of the small size and low initial cost, the X-band weather radar is utilized not only for meteorological users but also for vary users such as aviation, seaport and agriculture in both public and private sectors. NBRO, which is providing landslide early warning, can be a most important user in Sri Lanka. By using the X-band weather radar, the accuracy of landslide early warning will be drastically improved especially in mountainous region.

FURUNO Electric Co., Ltd. proposed "SDGs Business Model Formulation Survey for Strengthening Landslide Warning, using X-band Dual Polarization Weather Radar in Sri Lanka" to JICA in January 2021, and was accepted in April. Now the project is under preparation. We will clarify the effectiveness and efficiency as well as issues to implement the X-band weather radar system in Sri Lanka through the project.

5. References

1. JICA (2016). Preparatory survey report on the project for the establishment of a Doppler weather radar network in the Democratic Socialist Republic of Sri Lanka. Japan International Cooperation Agency.

An Overview of Slow-Moving Landslides; a Case Study from Diyanilla Landslide in Nuwara-Eliya District - Sri Lanka

JDSN Siriwardana[1]

[1]Geologist, National Building Research Organisation, Sri Lanka

Abstract

Rainfall triggering landslides is the most common type of natural mass movement disaster in Sri Lanka. There are several types of landslides that have been recorded in recent years, and among them, slow-moving landslides are recorded very rarely but affect the most. Slow-moving landslides creep just a few centimetres or meters per year, but they persistently alter the environment by changing the shapes of hills and rerouting drainage networks. Slow - moving landslides will likely remain a fixture of the landscape in a specific area where annual precipitation, geology, morphology, hydrology etc, are predicted to increase.

Such a slow moving landslide was recorded in 2007 in the Diyanilla area in Nuwara - Eliya District, which is re-activating time to time due to the causative factors. It has damaged significant properties within the area, thereby having a direct effect on day-to-day human activities.

For such types of slow-moving landslides, the application of costly structural mitigation or resettlement of vulnerable communities would be an ideal and permanent solution. But the resettlement plan may always affect the day-to-day lifestyle of the community members who are living under the risk of a landslide.

In this study, the causative factors that mainly affected to this landslide are studied generally. And according to the way of this landslide, the type of detailed investigations that are required to identify the features of the landslide and the possible structural and non-structural mitigation measures are discussed further to reduce the risk of the landslide.

Keywords: Slow moving landslide, Rainfall, Colluvium Soil, Bedrock

1. Introduction

A natural disaster can be defined as some rapid, instantaneous or profound impact from the natural environment upon the socio-economic system (Alexander 1993). Globally, it appears that the amount of death and damage in natural disasters is increasing due to natural and manmade causes. Landslides are the most common natural disasters in the central highlands of Sri Lanka, and they are caused by heavy rains caused by monsoon and inter-monsoon weather patterns. Soil instabilities triggered by rain fall in slopes (Houghton et al., 1996) that are composed of colluvium soils are the key hazards in the Nuwara-Eliya District.

Colluvium soil is a loose, un consolidated sediment that has been deposited at the base of hillslopes by the process of denudation (Pelletier, 2011). Numerous field studies have shown that small valleys dominate the drainage area of most soil-mantled hillslopes and greatly influence runoff and sediment transport processes. The valleys focus on the shallow subsurface, which may produce high pore pressures and saturation overland flow at the downslope ends of the valleys. The spoon-shaped surface topography also forces the convergence of soil material transported downslope by creep and biogenic transport processes and consequently, the valleys tend to develop a thick mantle of colluvium (Hack and Goodlett, 1960). And the thick deposit of colluvium soil tends to produce large, rapid debris flows that scour bedrock. Debris flows from thick colluvium in natural valleys have caused considerable destruction of property and loss of life (Brown, 1984).

This type of movement of the soil mass can vary according to the slope angle and the type of the moving material. As a result of this moving process, rapid movement and slow movement of debris can be expected. Those slow-moving landslides rarely claim lives, but can inflict serious damage on houses and infrastructure. And although they may amble along for months or years, they can also speed up unexpectedly, with sometimes fatal consequences.

The most highlighted slow-moving landslide among those was the Diyanilla landslide at Harasbedda, first recorded in 2007 and 2011. It damaged a segment of the Ragala - Walapane main road, more than twenty houses, tea fields and vegetable cultivated lands in the area. From time to time in the monsoon rain period, the movement of the landslide is reactivating and slightly damaging to the properties, hence it may create major social and economic issues that affect a significant number of communities. Structural and non-structural mitigation measures are applicable to reduce the risk of a slow moving landslide.

However, many of the measures, such as resettlement or application of structural elements for mitigation of identified potential landslide areas are costly and time consuming. Additionally, the use of such measures for a spatially distributed phenomenon like a landslide having a wide range of risk categories is an extremely difficult and challenging task. Therefore, in line with the four priorities of a Sendai Framework for Disaster Risk Reduction 2015 - 2030, a Community Based/ Managed Landslide Early Warning Project (CBLEWP) can be implemented for this type of slow-moving landslide to reduce the risk of the landslide. The target of establishing a community-based landslide early warning system is to make people aware of the vulnerable communities and to establish a systematic preparedness plan for self - evacuation before an event happens.

This research focuses on the Diyanilla landslide with the scope of evaluation of geological causative factors that were associated with the failure and introduces automated landslide data monitoring instruments to the landslide area and implements a methodology to evacuate the vulnerable community from a community based landslide early warning system by measuring the rainfall data from a manual rain-gauge. This evacuating procedure will be applicable until the data obtained from the installed site-specific automated landslide data monitoring instruments is analyzed and a structural mitigation measure designed to reduce the risk of the slow moving landslide.

2. Study Area

The affected area belongs to the Harasbedda and Palapathana Grama Niladhari Divisions of the Walapane Divisional Secretariat in the Nuwara-Eliya District of the Central Province of Sri Lanka (Figure 01). The area is accessible via the Nuwara-Eliya - Walapane main road (B 332, B 413), and it is located between the 67^{th} and 68^{th} kilometers of this main road, which serves as the main access to the Walapane, Nildandahinna, Adhikarrigama and Keerthibandarapura areas.

The study area is located in the Central highlands of Sri Lanka, which has a unique landscape and rainfall patterns. The average annual rainfall in the area varies between 2,500 mm and 3,000 mm. The average annual temperature of the area is about 16 ^{o}C - 24 ^{o}C, whereas the temperature may drop in some periods with the increase in elevation in mountainous terrain. The terrain is very rugged, with steep escarpments covering about 50% of the area on the upper slopes. The bedrock is often exposed, while in the upper sections of the escarpments there is a thick cover of colluvium deposits with various sizes of boulders. Bedrock is often exposed, while in the upper sections of the escarpments there is a thick cover of colluvial deposits with various sizes of boulders. Bedrock exposures in some areas have steep sides and are often dome-shaped exposures of bedrock that cover over 5% of the area. The general slope angle of the area is 25 to 35 degrees.

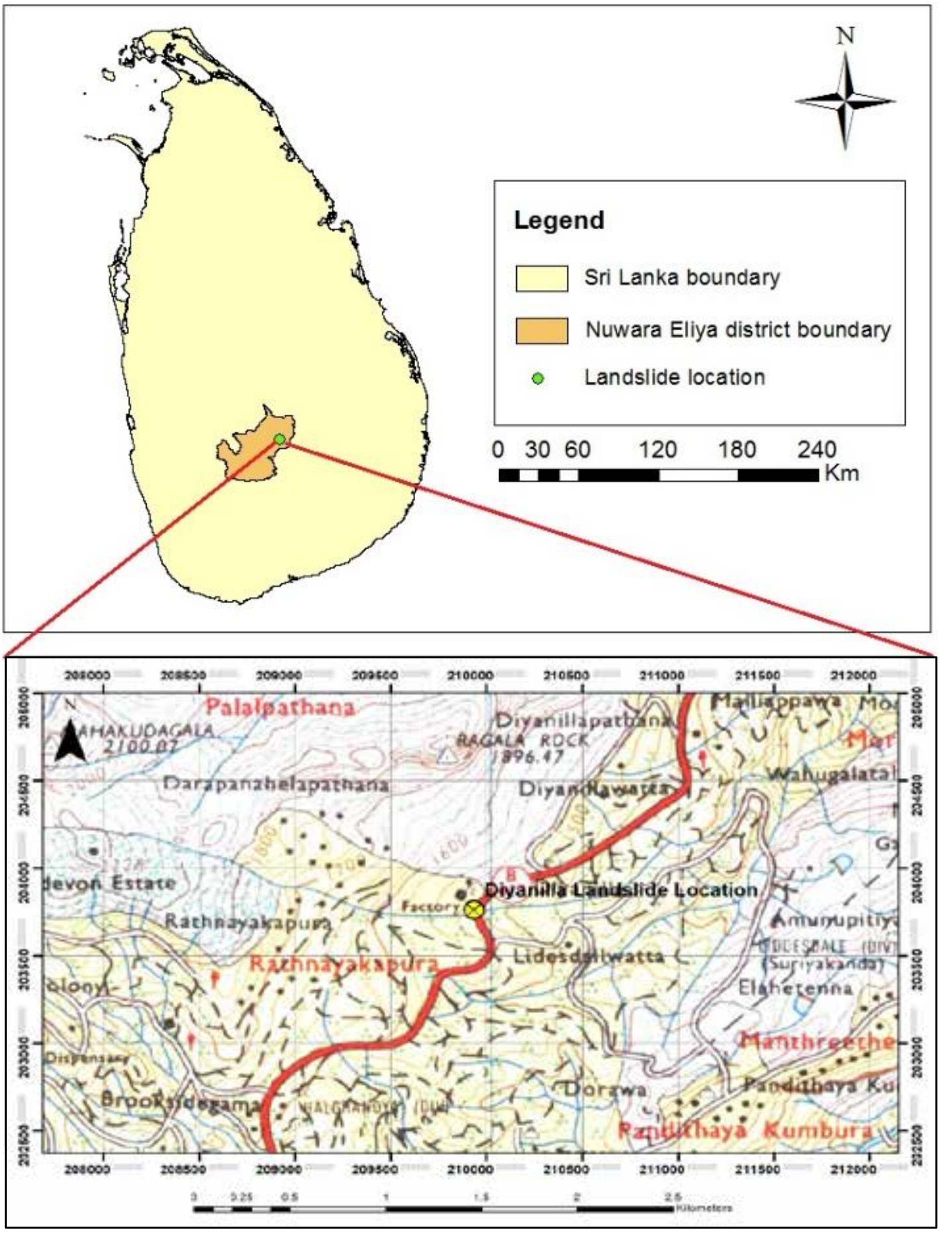


Figure 01: Location Map of the Diyanilla landslide (Source - sheet no. 62, Surveying department Sri Lanka

The study location is having prominent bedrock outcrop situated in the direction of intermediate slope of foliation plane. Low to medium weathering conditions of the soil and the bed rock present in the study area is in partially weathered condition. Mostly the bedrock outcrops were identified above the crown area of the landslide. And the studied landslide location is consists with dry valleys and ridges whereas the land use of total area consists with vegetable cultivation, home garden and tea estates. Upper most area of the landslide (initiation area) consists with vegetable cultivation with improper surface drainage systems with prominent erosional characteristics of the soil. Whereas the lowermost area of the landslide (depositional area) consists with tea estates with proper drainage systems and minimum soil erosional activities. Middle area of the landslide (flow path) may having thick colluvium deposit which is using for vegetable cultivation and it consists with houses and home gardens of the villagers (Figure 02).

GPS coordinates of the study area is N 7⁰ 02' 05.33", E 80⁰ 51' 49.12" and the elevation from the mean sea level is 1516 m. Study area lies on the Hanguranketha sheet of 1 : 50,000 topographic map (sheet no. 62) published by the surveying department Sri Lanka and on the map no. 14 of 1 : 100,000 scale Geology Map published by the geological survey and mines Bureau, Sri Lanka. According to the 1 : 50,000 Landslide Hazard Zonation Map published by National Building Research Organisation (NBRO) the affected area lies on landslides are to be expected category.

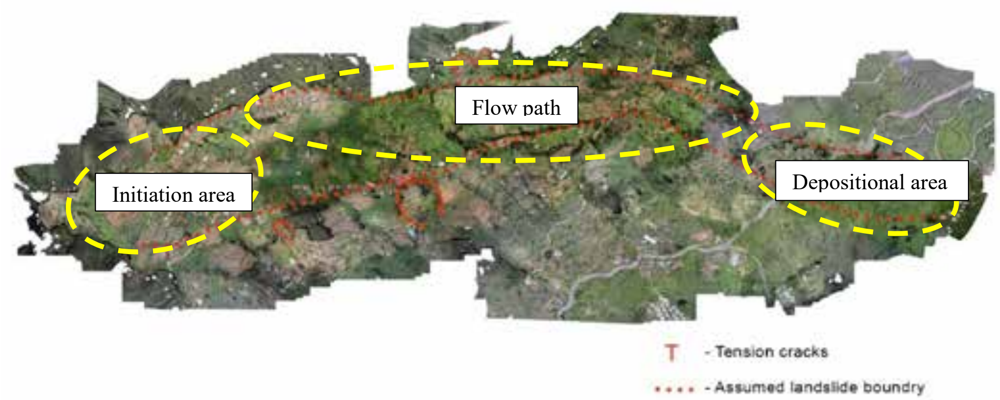


Figure 02: Initiation area, flow path and depositional area of the landslide

3. Methodology

Available literature data for the study area was collected and studied prior to the detailed field investigations. The selected study area was subjected to a series of field inspections and UAV surveys by an expert team comprised of geologists and engineers. During the field investigation, geological, geomorphological, hydrological, structural and lithological characteristics of the site were observed and identified as important factors for the occurrence of the landslide. Topographic maps and satellite images are important data sources to get an idea of the terrain conditions. Along with those landslide hazard zonation maps, geological maps and UAV images were further used to obtain a better understanding of Regional factors that were affected by the incident.

Details mapping of the rock type, weathering grade of the underlying rocks, type of soil existing in the terrain, land use pattern, peripheral margin of the landslide, details of the assumed landslide initiation area, flow path and the depositional area were collected during the detailed mapping. The geological data collected during fieldwork and UAV surveys was compared to a 1:100,000 scale geological map created by the Geological Survey and Mines Bureau (GSMB).

For the community based landslide early warning project, manual rain gauges demarcated with warning levels were distributed to the community leaders after preparing the community map in the community of Dianilla area. Locations for installation of rain gauges were determined based on community distribution and risk category, and three rain gauges were distributed throughout these two Grama Niladari Divisions. Rainfall thresholds that were defined by the National Building Research Organisation (NBRO; 75-99 mm/day - Watch; 100 - 149 mm/ day- Alert; 150 mm/day or above/ 75 mm/hour; Evacuation) are given to the vulnerable community for self-decision making.

Finally, a special meeting was conducted for the selected community leaders (response team) to educated them for their special responsibility such as operating, monitoring and maintaining of rain gauge, data recording into a special format provided by NBRO, functioning of early warning system, decision making process with communicating with NBRO and dissemination of final warning message to vulnerable community. It is planned to prepare and install a landslide early warning response map with a preparedness plan based on the community risk map, and to install it in an open area within the vulnerable community. This map will include roads, important locations such a temples, landslide susceptible areas and safe areas, locations of houses, locations of rain gauges, evacuation routes and evacuation centres, as per the operational manual.

Additionally, automated rain-gauges, multi-point inclinometers, strain-gauges, data-loggers , extensometers with moisture sensors and alert units that will be linked to the web based monitoring system with a siren will be installed in this area by Japanese OSASI TECHNOS Inc to have redundant systems for early warnings after carrying out several appropriate geotechnical investigations.

4. Site Specific Geology

The Precambrian crystalline rocks of Sri Lanka can be categorized into three major and one subordinate lithostratigraphic units (Kroner et. al., 1993). Namely,

I. Highland Complex (HC)

II. Wanni Complex (WC)

III. Vijayan Complex (VC) and

IV. Kadugannawa Complex (KC)

The study area is located in the Central highlands of Sri Lanka and, according to the geological setting of the Island, it is part of the Highland complex.

The physiography of the study area can be seen as a prominent mountainous range with broad u-shaped valleys that have severe erosional features. The weathering type and grade of the soil in the study area are in prominent conjunction with the vegetable cultivation of villagers. High precipitation in the area may accelerate the high weathering conditions of the soil, as well as the weathering conditions of bedrock exposures within the area. So, in the uppermost part of the area containing minor impurities, moderately weathered quartzo feldspathic gneiss bedrock exposures oriented in an intermediate dip slope were identified (Figure 03). Colluvium deposit in the middle part of the area covers the underlying bedrock, and no prominent foliation plane of the bedrock was observed in the scarp, body and toe of the landslide.

The entire area is spread over about 1.5 km^2 and consists of a thick colluvium deposit. The uppermost part of the study area has huge bedrock exposures, and the lower most area has a colluvium soil deposit that has a depth of more than 4 meters. Springs and

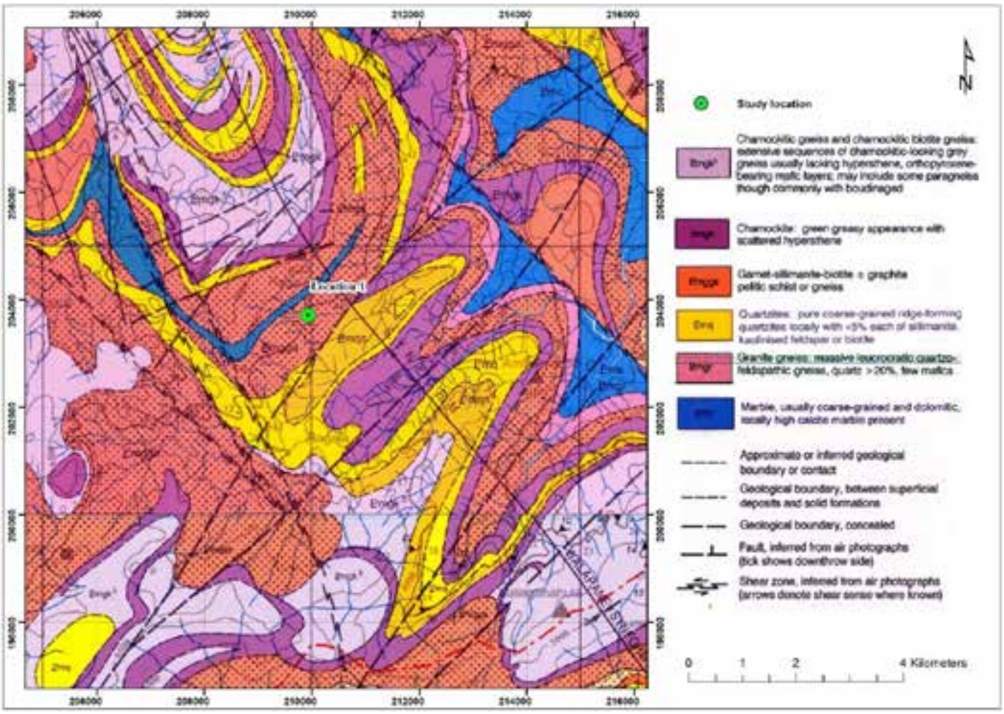


Figure 03: Geology map of the study area published by Geological Survey and Mines Bureau

seepages abound, as does a fluctuating groundwater table, and boulders ranging in size from 1-3 m are scattered throughout the area. High feldspar content in the bedrock tends to accelerate the weathering grade of the soil.

5. Results and Discussion

Some of the causes of the landslide include geological factors, morphological factors, physical factors, and factors associated with human activity. When considering the causes of slope movement, particularly the initiation of movement, may require a set of factors, usually associated with groundwater and surface runoff. Surface runoff is in conjunction with the annual precipitation of the area, and hence the ground water fluctuation may happen due to the infiltration from the rainfall pattern. As well, landslides may occur due to the removing of material from the base, loading of material at the top, erosion, poor land use pattern or soil cover, addition of water to a slope from irrigation, roof downspouts, poor drainage, septic - tank effluent, canal leakage or broken water tanks.Failure has a major impact on the fluctuation of the ground water table in conjunction with the annual precipitation of the area.

Causes may be considered factors that make the slope vulnerable to failure or that predispose the slope to becoming unstable. The trigger is the single event that finally initiates the landslide. Thus, causes combine to make a slope vulnerable to failure, and the trigger finally initiates the movement. Thus, the causes of the Diyanilla landslide are high weathering grade, thick colluvium deposit, rapid fluctuation of the ground water table and human activities such as vegetable cultivation. The triggering event of the landslide is monsoon rain subjected to the landslide terrain.

From the analysis of collected results within the study area, the movement of the landslides was observed from the point of view of different stages of landslide activity, such as the pre-failure stage, failure stage, post-failure stage, and reactivation stage. The pre-failure stage of this landslide occurred about 6 years ago, and during that period some initial crack developments within the buildings appeared. After that, from time to time, the landslide may show slow movement along the slip surface.

The processes of landslide debris movement on hillslopes, the type of the colluvium soil deposit, and land use pattern may affect the conditions of the landslide.

Landslide debris movement and the slope form after land sliding in the study basins varied in accordance with lithology. Therefore, the presence of rock types with high feldspar content and the presence of marble layers nearby the study area may having a direct influence of the landslide within the area.

The slope stability of the area is one of the major factors affecting the landslide, whereas the slope stability is ultimately determined by two factors, such as the angle of the slope and the strength of the materials on it. So the study area consists of heavy colluvium deposits and the moderate angle of slope may result in the slow-movement rather than rapid movement of the landslide.

Apart from applying structural mitigation measures to a large-scale slow-moving landslide, the establishment of a comprehensive Community-Based Landslide Early Warning System helped to raise awareness of the vulnerable communities and enhance the safety and confidence of the people living in this area. This is also considered the lowest cost and most practical method that can be used to reduce the risk of communities since the decisions are taken and the real-time activity is done by the vulnerable community rather than waiting for the decisions by officers away from the site.

6. Recommendations

For the occurrence of the Diyanilla landslide, it is clearly understandable that several causative factors and triggering factors are present, while geological, structural influence, and cumulative rainfall are the most important.

Important influences on the movement of a landslide include the shape, roughness, and composition of a slide's underside, or base; the proportions of the base to the sides; and the slide's depth, especially in relation to the water table.

To study this slow moving landslide further, advanced geotechnical investigations should be carried out. Borehole investigations could be applicable to identify the behaviour of sub surface soil strata and borehole data can be used to identify the locations within the area to install the landslide monitoring instruments where appropriate.

After carrying out geotechnical investigations, automated rain gauges, multi-point inclinometers, strain gauges, data-loggers, and extensometers with moisture sensors should be installed and collect the data continuously within 2 - 3 years, so that structural mitigation measures can be implemented to reduce the risk of the slow moving landslide in the Diyanilla area. In this context, the establishment of a non-structural risk communication mechanism such as a community-based landslide early warning system and installing a landslide early warning response map to evacuate people to a safer place under heavy rainfall can be implemented in the study area as practically feasible as one of the risk reduction measures.

7. Acknowledgement

Assistance by the Landslide Research and Risk Management Division of National Building Research Organization and OSASI company (Japan) for conducting fieldwork and UAV surveys are thankfully acknowledged.

8. References

1. Alexander, D. 1993: Natural disasters. London: UCL Press. Volume: 19 issue: 2, page(s): 287-288
2. Amaratunnga G.K. 1994. Negative Impact of Landslides on Environment.Proceedings, National Symposium on Landslide in Sri Lanka Volume 01, National Building Research Organization, Colombo, Sri Lanka, Pp. 207–210.
3. Brunetti, M., Buffoni, L., Mauger, M., Nanni, T. 2001a. Precipitation Intensity Trends in Northern Italy.International Journal of Climatology 20: 1017–1031.
4. Brunetti, M., Mauger, M., Nanni, T. 2001b. Changes in Total Precipitation, Rainy Days and Extreme Events in Northeastern Italy.International Journal of Climatology 21: 861–871.

5. Cruden,D.M., Varnes, D.J. (1996), Landslide Types and Processes, Special Report , Transportation Research Board, National Academy of Sciences, 247:36-75
6. Dahanayaka, K. (2003). Landslides in the Sri Lankan Highlands. Department of Geology, University of Peradeniya, Sri Lanka.
7. Dissanayake A.K. 1998. A Study of Geotechnical Aspects of some Sri Lankan Landslides. A Master of Philosophy Thesis, Department of Civil Engineering, University of Peradeniya, Peradeniya, Sri Lanka.
8. Domroes, M., Ranatunga, E. 1993. Analysis of Inter-station Daily Rainfall Correlation During the Southwest Monsoon in the Wet Zone of Sri Lanka.Geografiska Annaler 75A (3): 137–148.
9. Groisman, P.Y., Karl, T.R., Easterling, D.R., Knight, R.W., Jamason, P.F., Hennessy, K.J., Suppiah, R., Page, C., Wibig, M., Fortuniak, J., Razivaev, K., Douglass, V.N., Forland, A., Zhai, E.J. 1999. Changes in the Probability of Heavy Precipitation: Important Indicators of Climatic Change.Climate Change 42: 243–283.
10. Gunatilake, J., Iwao, Y. and Yamasaki, T. (2002). Relationship of the faulting to creep movement of Iwakura landslide in Saga, Japan. Journal of the Japan Landslide
11. Herath S. and Ratnayake, U.R. 2004. Monitoring Rainfall Trends to Predict Adverse Impacts—a Case Study from Sri Lanka (1964–1993).Global Environmental Change 14: 71–79.
12. Houghton, J.T., Meira Filho, L.G., Callander, B.A., Harris, N., Kattenberg, A., Maskell, K. (eds.). 1996. IPCC Climate Change.The IPCC Second Assessment Report. Cambridge University Press, New York.
13. Hussain, M. (2010). Analysis and behavior of preexisting landslides.Ph.D. Thesis, Universit of Illinois at Urbana-Champaign, USA, 308 p.
14. Jon D. Pelletier Victor R. Baker; The role of weathering in the formation of bedrock valleys on Earth and Mars: A numerical modeling investigation; First published: 19 November 2011 Journal of Geophysical Research
15. Kotapola J. 1994. Landslides in Sri Lanka in the 21st Century.Proceedings, National Symposium on Landslide in Sri Lanka Volume 01. National Building Research Organization, Colombo, Sri Lanka, Pp. 161–168.
16. Lakmali D.G.E.D, Palamakubure L., Bandara K.N., (2017), Characterization of Nawalapitiya landslide, in the Kandy District, 8th annual NBRO symposium, pp 15-25.
17. Manton, M.J., Della Marta, P.M., Haylock, M.R., Hennessy, K.J., Nicholls, N., Chambers, L.E., Collins, D.A., Daw, G., Finet, A., Gunawan, D., Inape, K., Isobe, H., Kestin, T.S., Lefale, P., Leyu, C.H., Lwin, T., Maitrepierre, L., Ourprasitwong, N., Page, C.M., Pahalad, J., Plummer, N., Salinger, M.J., Suppiah, R., Tran, V.L., Trewin, B., Tibig, I., Yee, D. 2001. Trends in Extreme Daily Rainfall and Temperature in Southeast Asia and the South Pacic: 1961–1998.International Journal of Climatalogy 21: 269–284.
18. Ministry of Forestry and Environment of Sri Lanka. 2001.National State of the Environment (SoE) of Sri Lanka in 2001. UNEP report, Colombo, Sri Lanka.
19. Palincsar, A. S., & Brown, A. L. (1984). Reciprocal teaching of comprehension-fostering and comprehension-monitoring activities. Cognition and Instruction, 1(2), 117–175, Society, 39, no. 2002, pp 212-223.
20. Stark, T. D., Choi, H., and McCone, S. (2005a). Drained shear strength parameters for analysis of landslides. J.Geotech.eoenviron. Eng. 131(5):575-588.

Planar Failure Induced landslide: A Case Study from Malapattawa Area, Walapane in Nuwara-Eliya District

JDSN Siriwardana[1], HMBB Wijekoon[1]

[1]Geologist, National Building Research Organisation, Sri Lanka

Abstract

Rainfall triggering landslides are the most common type of natural mass movement disasters in Sri Lanka and such type of landslides are mostly associated with colluvium soil deposits. Apart from the colluvium soil terrains, landslides can occur within the residual soil too. One of these landslides are observed as planar failures in the residual soil terrain. Bedrock geology and structural dis continuities of the underlying rock formations may control the planar failure induced landslide in a specific area. Precipitation may act as a triggering factor for the movement within the bedding planes thus the development of clay minerals due to the seepages through the foliation plane of the bedrock outcrop. Removal of toe support of the bedding plane may originate the planar failure as a result of development activities including widening of roads the area. Such type of planar failure induced landslide was reported in Malapattawa area in Nuwara-Eliya District on 30th November 2019 at 7:30 pm on Saturday. An earth mound along the Thannakumbura-Rikillagaskada - Ragala main road (B 413) in the Munwatta area buried a house resulting four deaths due to the incessant rainfall within the area. In this study the causative factors that mainly control this planar failure induced landslides are discussed.

To reduce the weight of the unstable mass it is applicable to remove the overburden considerably of the unstable area. Pocket netting and rock bolting with controlling the surface runoff over the slope can be introduced as a mitigation measures to this planer failure induced landslide in Malapattawa area in Nuwara-Eliya District.

Key words; Rainfall, Planar failure, Landslide, Bedding plane, Bedrock geology

1. Introduction

Most of the landslides occur within colluvium soil deposits, with rare occurrences of some residual soil deposits failing as a result of incessant rainfall within the area. Such types of landslides are controlled by underlying discontinuities in the rock slopes.

In rock slopes, various types of failures can occur such as plane, wedge, toppling and rock fall to name as the most common modes of failures (Tang et al., 2016; Lee and Wang, 2011; Yoon et al., 2002; Hoek and Bray; 1981, Hocking; 1976). Plannar failure generally occur in slopes formed by stratified rock formations. When a structural dis continuity plane dips towards the valley at an angle smaller than the slope face angle and greater than the angle of friction of the discontinuity surface (Tang et al., 2016; Kovari and Fritz, 1984) such type of failures can trigger.

The failure surfaces are obviously structural dis continuities such as bedding planes, faults, joints or the interface between bedrock and an overlying layer of weathered rock. Such type of dis continuity controlled cut slope failures are unusual within the residual soil.

Within recent times, numerous landslides have developed in the cut-slopes composed of soil mass developed from the in situ weathering of rocks as well as failures along the foliation plane existing along the Thannakumbura-Rikillagaskada - Ragala main road (B 413). Landslides occur on the underlying weathered metamorphic rocks are much common along the Thannakumbura – Rikillagaskada - Ragala main road (B 413) in the recent past.

The Thannakumbura-Rikillagaskada - Ragala main road, coursing from Ragala to Thannakumbura was constructed to provide access connecting the Nuwara - Eliya and Hanguranketha to the Kandy area of the Central Province. The major road cuts exist along this main road consists of variably dipping high-grade metamorphic rocks including charnokitic gneises with good foliation and fracture planes. Due to this geological and structural conditions, the area is highly prone to occurrence of planar failures and landslides along this main road.

Most of them caused severe damage to vehicular traffic, lives and properties of the people who live within 500 m distance from the main road. Many of the landslides, which occur in the residual soil and weathered rock zones, are due to the existence of dip slope of the foliation plane.

Most of these planar failure induced landslides in the Nuwara-Eliya District of Sri Lanka are occurred as rainfall triggering events. Rainfall is a principal instability triggering factor in rock slopes (Ermias et al., 2017; Raghuvanshi et al., 2014; Dahal et al., 2006; Ayalew et al., 2004; Dai and Lee, 2001; Collison et al., 2000). This is evident from the fact that most of the slopes fail during rainy season (Ermias et al., 2017; Raghuvanshi et al., 2015; Raghuvanshi et al., 2014). Surface flow on upper slope due to rainfall will easily find its way through tension cracks to recharge the potential failure surface. Thus, instability in the slope will be induced.

With the onset of North-East monsoon, Sri Lanka received heavy showers and this heavy rain inundated most parts of the Northern, Eastern, North Central, Uva and Sabaragamuwa provinces of Sri Lanka. Heavy showers resulted in flooding, high winds and landslides in nine Districts of Sri Lanka. Some areas received more than 200 mm of rainfall during a day.

In the last North-East monsoon period, on 30th November 2019, heavy rainfall was reported in Kalutara 243 mm, Anuradhapura 172 mm, Kurunegala 188 mm, Kandy 124 mm and Ranorawa (Anuradhapura) 172 mm respectively. Rainfall data of the Munwatta gauging station revealed that the amount of continuous precipitation poured in to the area for five consecutive days from 25th to 30th exceeded 220 mm, prticularly, 113.5 mm rainfall received within 6 hours on same day.

Due to this continuous heavy showers, a landslide occurred at Walapane, in Nuwara - Eliya District on 30th November 2019. Four people were reported dead, three of them from the same family. The incident occurred at about 7:30 pm on Saturday when an earth mound along the Thannakumbura-Rikillagaskada - Ragala main road in the Munwatta area buried the house due to the incessant rains.

Operation of a “A” Grade rock quarry belongs to HUNAN Construction Engineering Group Corporation located about 50m ahead from the initiation area contributed to triggering of landslide (Figure 01).

The main objective of this study is to identify the main factors (causative and triggering) and their inter relationship that affected to the Malapattawa planer failuer induced landslide.

Figure 01: Rock quarry (left) with the landslide initiation area (right)

2. Study Area

The study area is located in the Central highlands of Sri Lanka which having the unique landscape and rainfall patterns. GPS coordinates of the study area is N 7^0 07' 32.96'', E 80^0 50' 06.77'' and the elevation from the mean sea level is 1,516 m. Study area lies on the Hanguranketha sheet of 1:50,000 topographic map (sheet no. 62) published by the surveying department of Sri Lanka and on the map no. 14 of 1:100,000 scale Geology Map published by the geological survey and mines bureau, Sri Lanka. According to the 1:50,000 Landslide Hazard Zonation Map published by National Building Research Organisation (NBRO) the affected area lies on "landslides are to be expected" category.

The affected area belongs to Andawela Grama Niladari Division of Walapane Divisional Secretariat in Nuwara-Eliya District of Central Province of Sri Lanka (Figure 02). Area can be accessed by travelling through Nuwara-Eliya-Udapussellawa main road (B 332) and Thannakumbura-Rikillagaskada-Ragala main road (B 413) and it is located in between the 50^{th} km post of this main road which is the major access to Walapane, Nildandahinna, Adhikarrigama and Thannakumbura areas.

Aaverage annual rainfall of the area varies between 2,500 mm-3,000 mm. Average annual temperature of the area is about 16 ^oC-24 ^oC whereas the temperature may drops in some periods with the increase of elevation in mountainous terrains. The terrain is very rugged with steep escarpments covering about 50% of the area in the upper slopes. The bedrock is often exposed in the upper sections of the escarpments, as well as the road cuts of the main road. Some areas were consisting of thick cover of colluvium deposits with various sized boulders. Bedrock exposures along the road cut is prominent which are covering over 50% of the area. General slope of the area directed towards west is about 40^o - 45^o degrees. Bed rock is clearly visible as Charnokitic gnieiss at the Upper slope of the main road. On top of that, reddish color residual soil layer with clay is available within the thickness of 0.5 - 1.0 m.

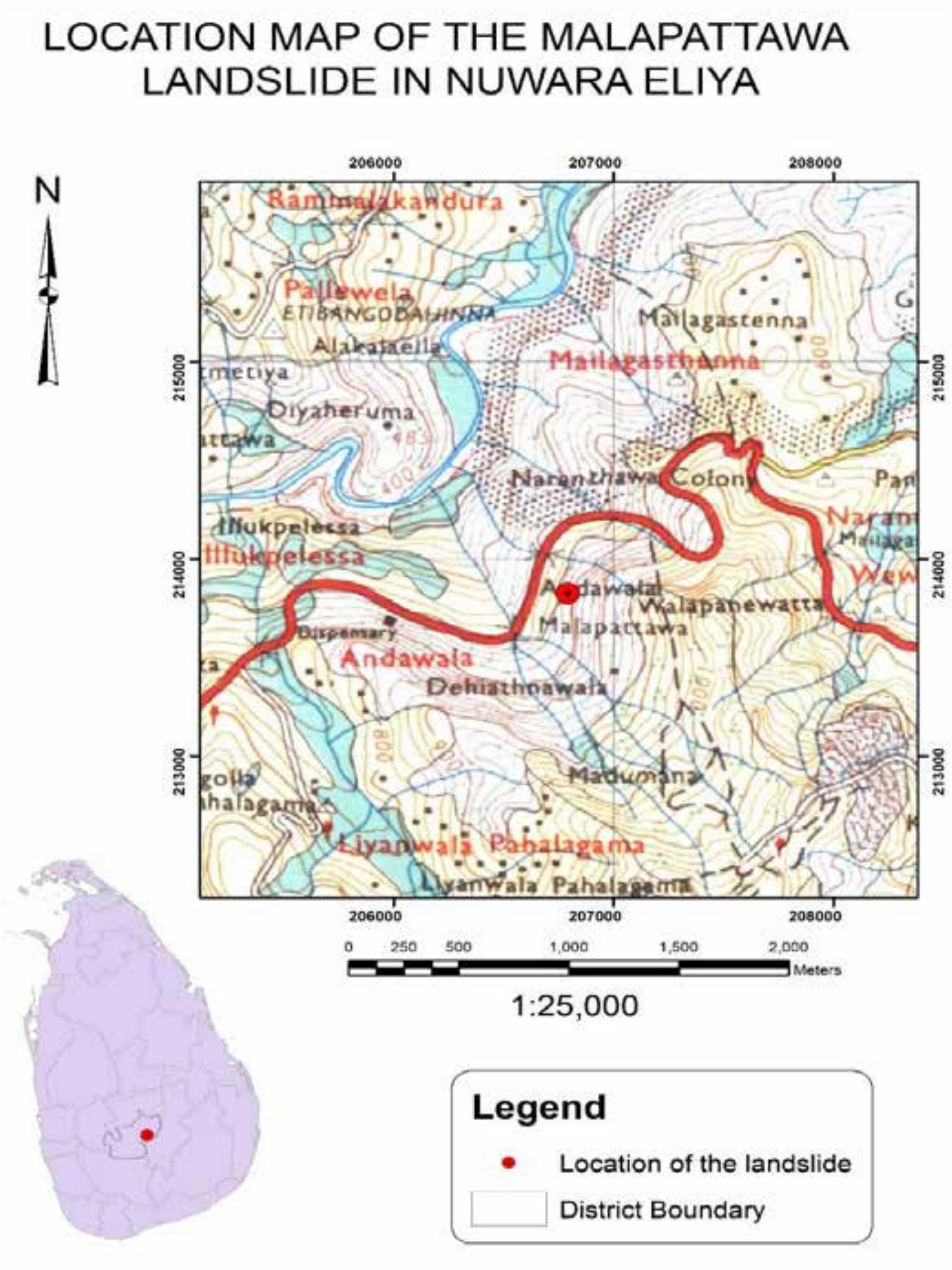


Figure 02 : Location map of the Malapattawa landslide

3. General Geology of the Study area

The bedrock is identified as Charnockitic gneiss (figure 03). The strike direction of the foliation plane is S 21^0 E and it is dipping towards 37^0 SW. Two joint patterns of the bedrock are identified and their orientations are as N60^0 W/ 79^0 NE and N80^0 W /85^0 NE.

Water seepages into the joints of the bedrock has caused the rock weathering along the joints and the foliation, which has led to the occurrences of clay minerals. Construction of the main road has made the exposing of the foliation to the road segment.

Such geological conditions have caused the unstable slope to be placed at the dip slope of the bedrock. Due to the heavy rainfall occurred at the incident date, high pore water pressure which is originated from the infiltration of higher amount of water into the joints has caused the separation of the rock fragments along weak joints and slipped towards the dip slope.

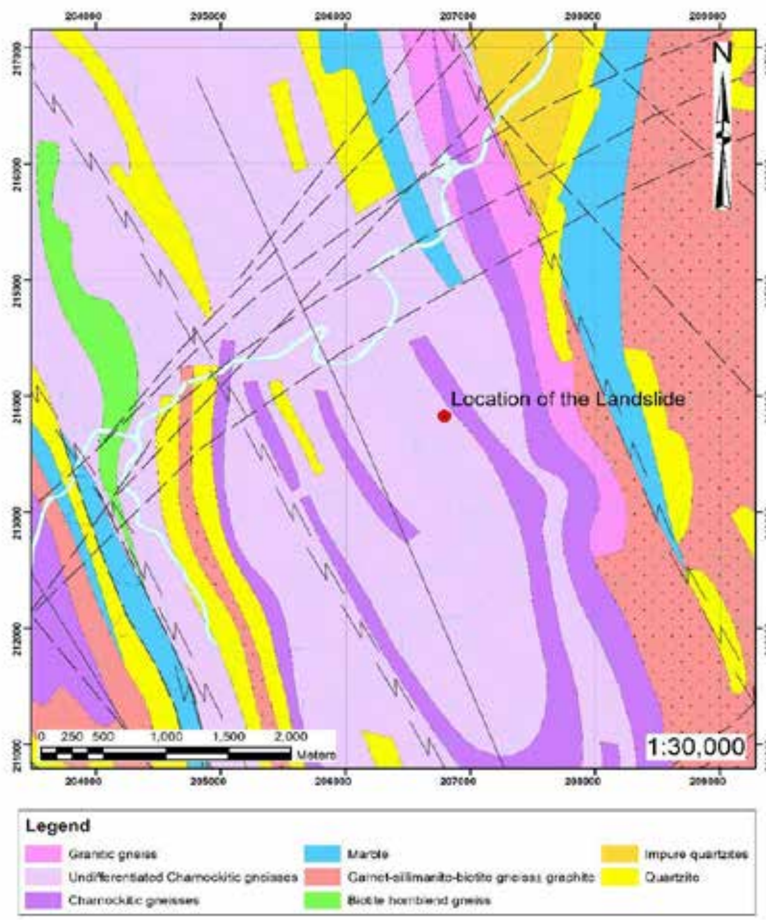


Figure 03 : Geology map of the Malapattawa landslide area

4. Methodology

The selected study area was subjected to field and UAV surveys by expert teams comprised of geologists and town planners of Landslide Research and Risk Management Division and Human Settlement Planning and Training division of NBRO. Geological, hydrological and lithological characteristics of the site was observed while rainfall data from NBRO automated rain gauges were collected to find the cumulative rainfall of the region experienced at the time of the disaster. The landslide hazard zonation maps were further used to verify the observations.

Available data for the study area was collected prior to the detailed field investigations. For identifying effective parameters in landslide incidence, field observations were conducted and during this period six parameters were recognized : bedrock geology, hydrology and drainage, surface overburden, slope angle range, land use and landforms. Already prepared factor maps of geology, overburden, slope, hydrology, land use and landform of study areas of Nuwara-Eliya District were used to evaluate the applicability of the evaluation.

Topographic maps and satellite images are important data sources to get an idea about the terrain condition and accessibility, prior to the field investigation. Topographic maps are in 1:10,000 scale and published by the Survey Department of Sri Lanka were used for further studies within the area.

In detailed geological studies, Geological data were gathered from 1:100,000 scale Geological map, established by Geological Survey and Mines Bureau (GSMB) and the map data were compared with data obtained from the field work. In the landslide location, details of the rock type, their weathering grade, type of dis continuity (foliation, joints, faults and beddings) and their orientations, dis continuity properties (intensity, persistence, infilling) were collected during the detailed mapping.

Details of slope dimensions were obtained by measuring the slope angles, slope heights and survey cross section. All these necessary data were gathered, as they are important in recognizing and selecting of precision and reliability of these factors in hazard zonation. For identifying effective parameters in landslide incidence, field observations were conducted and during this period six parameters were recognized : bedrock geology, hydrology and drainage, surface overburden, slope angle range, land use and landforms.

A risk rating system was used to assess the risk category of the road trace. Based on the risk assessment and the factor of safety, suitable remedial measures were proposed.

5. Results and Discussion

Road construction is the major manmade activity on the hill slopes (Ermias et al., 2017; Wang and Niu, 2009) where the slopes are cut in unplanned manner, leaving unsupported overhanging steep slopes. The natural slope stability is disturbed and instability in slope is induced (Tang et al., 2016) due to such type of unplanned road development activities. If kinematic conditions for plane mode of failure exist, the slope may easily fail.

However, there are some other aspects related to natural and manmade activities on slopes. Adding high water content to the slope by continuous precipitation, adding surcharge by constructing buildings and other civil engineering structures on the slopes, etc.

Such conditions will directly add to the weight of the siding mass and if kinematic conditions exists probability for slope failure will increase (Shukla et al., 2009). By considering this phenomenon, there were major two factors associated with this planar failure induced landslide. There are excess rainfall in the Malapattawa area and the toe support removal for the road construction activities.

Rainfall data of the Munwatta gauging station revealed that the amount of continuous precipitation poured in to the area for five consecutive days from 25th to 30th exceeded 220 mm. particularly, 113.5 mm rainfall received within 6 hours on same day (Figure 04). The incident happened at already identified high landslide potential having 20 houses facing the same situation.

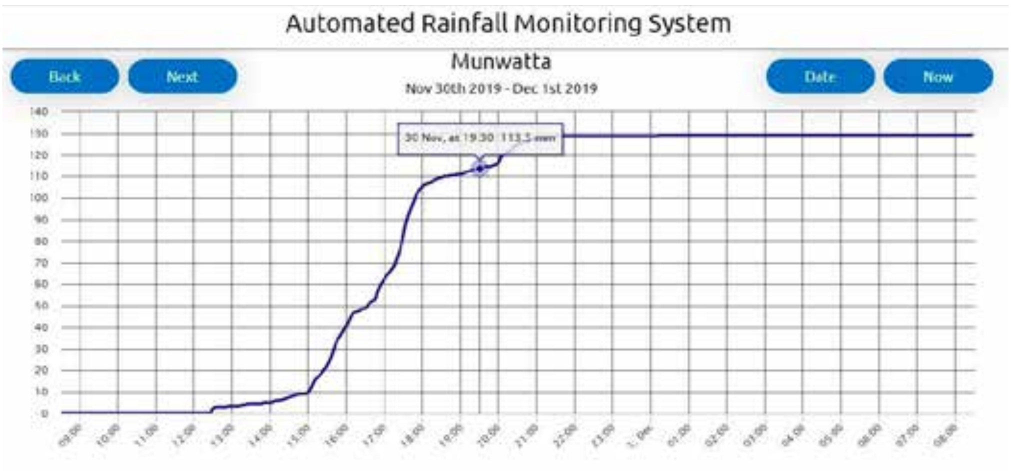


Figure 04: 24 hours rainfall data recorded Munwatta gauging station

Continuous precipitation of the area may cause water seepages into the joints of the bedrock. It has subjected the rock weathering along the joints and the foliation, which has led to the occurrences of clay minerals. Construction of the main road has made exposing of the foliation.

Such geological conditions have caused the unstable slope to be placed at the dip slope of the bedrock. Due to the heavy rainfall occurred at the incident date, high pore water pressure which is originated from the infiltration of higher amount of water into the joints has caused the separation of the rock fragments along weak joints and slipped towards the dip slope. Vibrational activities occurred from the nearest rock quarry due to the rock blasts may added an extra pressure to the rock slope which could support the movement of the slope. However, affection of this vibrational activity to the movement of the slope, should be studied further to become a scientific proof.

The house which was destroyed by the incident is at the direct downslope region to the incident place and the house was destroyed by the flow of rock and soil fragments from the incident.

6. Conclusion and Recommendations

Planar failure is a simple mode of failure in rock slopes, however due to complexity in geometry, variability in discontinuity characteristics, uneven distribution of water forces within the slope, surcharge and dynamic loading conditions, due to the removal of toe support for the road widening projects, the failure mechanism may become complex to assess.

The method to be applied for planar failure analysis may depend on several factors such as; governing parameters, complexity of geological conditions, geometric and hydrologic conditions, purpose for which slope stability has to be assessed, computational capacity and the capabilities of an evaluator to apply these techniques.

To reduce the weight of the unstable mass it can be applicable to reduce the thickness of the overburden of the unstable area prior to the geotechnical investigation data. As an active mitigation measure of rock fall threat, pocket netting can be applicable and rock bolting may suggest as a passive rock fall mitigation measure. Apart from that to control the surface runoff over the slope, cut-off drain has introduced to prevent the surface runoff towards the crack and divert the rain water to the cascade drains which are construct from top cut-off drain to the bottom road level.

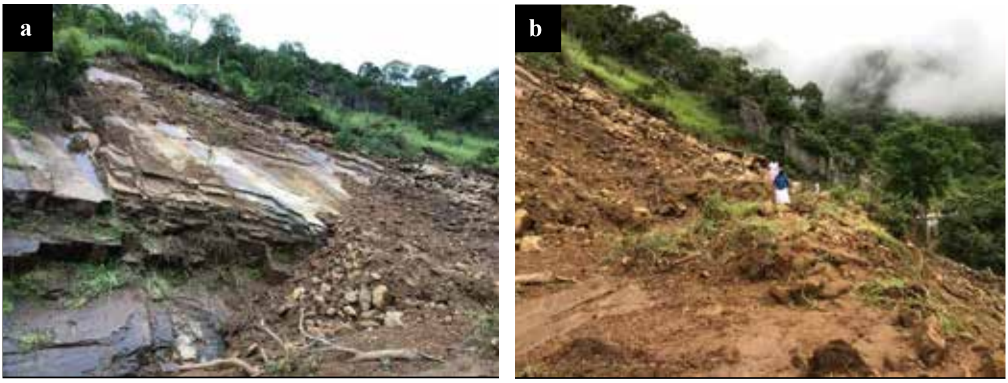


Figure 05 a,b : Malapattawa landslide

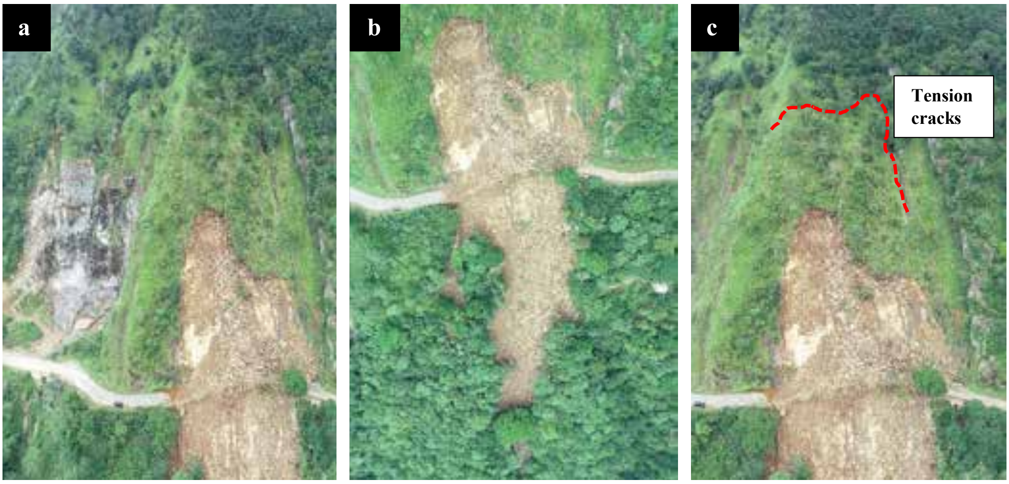


Figure 06 a,b,c : UAV images of the Malapattawa landslide

7. Acknowledgement

Assistance by the Landslide Research and Risk Management Division and Human Settlement, Planning and Training Division of National Building Research Organisation for conducting fieldwork and UAV surveys are thankfully acknowledged.

8. References

1. A.K. Alzo'ubi, Rock slopes processes and recommended methods for analysis; Int. J. GEOMATE, 11 (25) (2016), pp. 2520-2527
2. B. Ermias, T.K. Raghuvanshi, B. Abebe, Landslide Hazard Zonation (LHZ) around Alemketema Town, North Showa Zone, Central Ethiopia - A GIS based expert evaluation approach, Int. Jr. Earth Sci. & Engg., 10 (1) (2017), pp. 33-44
3. C.T. Turrini, P. Visintainer, Proposal of a method to define areas of landslide hazard and application to an area of the Dolomites, Italy. Eng. Geol., 50 (1998), pp. 255-265
4. C.Y. Lee, I.T. Wang Analysis of highway slope failure by an application of the stereographic

projection, Int. J. Environ. Chem. Ecol. Geol. Geophys. Eng., 5 (3) (2011), pp. 122-129

5. Collison, S. Wade, J. Griffiths, M. Dehn, Modelling the impact of predicted climate change on landslide frequency and magnitude in SE England, Eng. Geol., 55 (2000), pp. 205-218
6. D.P. Salunkhe, G. Ch van, R.N. Bartakke, P.R. KothavaleAn overview on methods for slope stability analysis, Int. J. Eng. Res. Technol., 6 (3) (2017), pp. 528-535
7. E. Eberhardt, D. Stead, J.S. Coggan, Numerical analysis of initiation and progressive failure in natural rock slopes—the 1991 Randa rock slide, Int. J. Rock Mech. Min. Sci., 41 (2004), pp. 69-87
8. E. Hoek, J.W. Bray, Rock Slope Engineering (Revised Third Edition), Institute of Mining and Metallurgy, London (1981), p. 358
9. F.C. Dai, C.F. Lee, Terrain-based mapping of landslide susceptibility using a geographical information system: a case study, Can. Geotech. J., 38 (2001), pp. 911-923
10. F.G. Bell, Engineering Geology, (second ed.), Butterworth-Heinemann, Great Britain (2007), p. 581
11. G. Hocking, A method for distinguishing between single and double plane sliding of tetrahedral wedges, Int. J. Rock Mech. Min. Sci. Geomech. Abstr., 13 (1976), pp. 225-226
12. Goodman, R. E. 1989, Introduction to Rock Mechanics, University of California at Berkeley, pp. 562.
13. H. Tang, R. Yong, M.A.M. Ez EldinStability analysis of stratified rock slopes with spatially variable strength parameters: the case of Qianjiangping landslide, Bull. Eng. Geol. Environ. (2016),
14. J.T. Markland, A useful technique for estimating the stability of rock slopes when the rigid wedge sliding type of failure is expecte, Imp. Coll. Rock Mech. Res. Rep., 19 (1972), p. 10
15. Kovari, K., Fritz, P., (1984). Recent developments in the analysis and monitoring of rock slopes. In: IVth International Symposium on Landslides, Toronto.
16. L. Ayalew, H. Yamagishi, N. Ugawa, Landslide susceptibility mapping using GIS-based weighted linear combination, the case in Tsugawa area of Agano River, Niigata Prefecture, Japan, Landslides, 1 (2004), pp. 73-81
17. M. Ahmadi, M. Eslami; A new approach to plane failure of rock slope stability based on water flow velocity in discontinuities for the Latian dam reservoir landslide, J. Mt. Sci., 8 (2011), pp. 124 130
18. M.J. Selby, A rock mass strength classification for geomorphic purposes: with tests from Antarctica and New Zealand, Zeitschrift für Geomorphologie, 23 (1980), pp. 31-51
19. N. Barton, S. Bandis, Review of predictive capabilities of JRC-JCS model in engineering practice, A.A. Balkema (Ed.), Proceedings of International Conference on Rock Joints, Loen, Norway (1990), pp. 603-610
20. R. Anbalagan; Landslide hazard evaluation and zonation mapping in mountainous terrain, Eng. Geol., 32 (1992), pp. 269-277
21. R. Chowdhury, Geotechnical Slope Analysis, CRC Press/Balkema, The Netherlands (2010), p. 737

22. R.B. Johnson, J.V. Degraff, Principles of Engineering Geology, John Willy and Sons, New York (1991), p. 497
23. R.J. LisleCalculation of the daylight envelope for plane failure of rock slopes Ge'otechnique, 54 (4) (2004), pp. 279-280
24. R.K. Dahal, S. Hasegawa, T. Masuda, M. Yamanaka, Roadside Slope Failures in Nepal during Torrential Rainfall and their Mitigation. Disaster Mitigation of Debris Flows, Slope Failures and Landslides, (2006), pp. 503-514
25. S.K. Shukla, S. Khandelwal, V.N. Verma, N. Sivakugan, Effect of surcharge on the stability of anchored rock slope with water filled tension crack under seismic loading condition, Geotech. Geol. Eng., 7 (4) (2009), pp. 529-538
26. Shukla, V., Doyon, Y., Miller, J. et al. Precise genome modification in the crop species Zea mays using zinc-finger nucleases. Nature 459, 437–441 (2009).
27. T.K. Raghuvanshi, J. Ibrahim, D. AyalewSlope stability susceptibility evaluation parameter (SSEP) rating scheme – an approach for landslide hazard zonation, J. Afr. Earth Sci., 99 (2014), pp. 595-612
28. T.K. Raghuvanshi, L. Negassa, P.M. KalaGIS based grid overlay method versus modeling approach – a comparative study for Landslide Hazard Zonation (LHZ) in Meta Robi District of West Showa Zone in Ethiopia, Egypt. J. Remote Sens. Space Sci., 18 (2015), pp. 235-250
29. T.K. Raghuvanshi, N. SolomonA Sensitivity Analysis of a Natural slope having Planar mode of failure, J. Ethiop. Assoc. Civil Eng., 4 (1) (2005), pp. 27-40
30. W.S. Yoon, U.J. Jeong, J.H. Kim, Kinematic analysis for sliding failure of multi-faced rock slopes, Eng. Geol., 67 (2002), pp. 51-61
31. X. Wang, R. Niu Spatial forecast of landslides in three gorges based on spatial data mining, Sensors, 9 (2009), pp. 2035-2061
32. X.L. Yang, J.F. ZouStability factors for rock slopes subjected to pore water pressure based on the Hoek-Brown failure criterion, Int. J. Rock Mech. Min. Sci., 43 (2006), pp. 1146-1152
33. Y.C. Liu, C.S. Chen, A new approach for application of rock mass classification on rock slope stability assessment, Eng. Geo., 89 (2007), pp. 129-143

Development of Local Rainfall Thresholds for Landslide Occurrence in Sri Lanka; A Case Study in Kalu River Basin

WDGDT Rajapaksha[1], Wasantha Senadeera[2], T Wada[3], NH Priyankara[4], HAG Jayathissa[2]

[1]Scientist, National Building Research Organisation, Sri Lanka
[2]Senior Scientist, National Building Research Organisation, Sri Lanka
[3]Consulting Engineer, Earth System Science Co. Ltd. Japan
[4]Senior Lecturer, University of Ruhuna, Sri Lanka

Abstract

Landslides constitute one of the prominent geohazards that cause severe damage to property and loss of life every year across the World. Rainfall is identified as the most important and frequent triggering factor of landslides. Rainfall contributes to the triggering of landslides by the means of water infiltration into the sub soil, which causes an increase in pore water pressure and hence, a decrease in soil shear strength. Therefore, the determination of rainfall thresholds seems to be an essential work to develop an effective landslide early warning system. In this research, we tried to develop Local rainfall thresholds for Kalu River Basin with the aid of past landslides and associated cumulative rainfall. For the analysis, 37 landslide events that occurred after 2015 were utilized and rainfall records were based on the 10 number of rain gauging stations within the basin. According to the obtained results, 89% of the landslides in the study area were initiated with 2 - 4 hour intense rainfall which was followed by cumulative rainfall > 260 mm for a maximum of 3 days. The rest of 11% of landslides were initiated with suddern rainfall event with relatively low cumulative value < 190 mm and high hourly rainfall value > 70 mm. Further, these 11% of landslides were occurred in already unstabilized slopes indicating that intense short term rainfalls together with unstable slopes cause landslides even with relatively lower cumulative rainfall.

Finally, as these different features in different scale more research is recommended to investigate the relationship between rainfall and other physical characteristics to trigger a landslide event

Keywords: Cummulative rainfall, Hourly rainfall, Landslide

1. Introduction

Landslides are one of the prominent and devastating natural hazards in the mountainous terrains of the world which causes substantial damage to both property and lives, and often leading to loss of lives. In many Countries landslides alone generate a yearly loss of property larger than that of any other disaster. According to the available previous disaster records, the annual death toll of non-seismic landslide events is approximately 1600, and the majority of these occurring in Asia (Thiebes et al., 2017). In the case of Sri Lanka, major landslides that occurred during the past three to four decades have caused to death of more than 1,500 human lives making over 200,000 homeless (Kumara et al., 2018).

The occurrence of landslides mainly depends on the basic characteristics of slopes and anthropogenic factors while triggering factors support to increase the driving force. In the case of Sri Lanka, rainfall acts as the main triggering factor. The seasonal distribution of landslides in Sri Lanka demonstrates a clear link with the distribution of the rainfall. The rapid infiltration of rainwater facilitates soil saturation and a temporary rise in pore - water pressures and thus, decreasing soil shear strength is generally believed to be the mechanism by which most landslides are generated during storms (Bhattacharjee, 2017; Nafarzadegan et al., 2013; Wieczorek, 1996).

According to the previous landslide incidents, rainfall triggered landslides occurred after a certain threshold value. White et al; (1996) define a threshold as the minimum or maximum level of some quantity needed for a process to take place or a state of change. The lowest level below which a process does not take place is defined as the minimum threshold while the levels above which a process always takes place represent the maximum threshold (Rao and Singh, 2015). In the case of rainfall triggering landslides, the threshold is the lowest level of rainfall above which landslides can occur. Therefore, accurately the derivation of the rainfall threshold is vital to the prediction of landslide occurrence and to reduce disaster damage.

Literature reveals the numerous attempts that have been taken by researchers to predict the rainfall - induced shallow landslides using empirical rainfall thresholds or spatially distributed, physically-based numerical models. However, empirical methods seem to be more approachable compared to that of physical models to develop rainfall thresholds on a Regional and Local scale as physical models require detailed knowledge of input parameters such as soil parameters, hydrology, morphology and lithology, which are very difficult to acquire an accurate manner (Berti et al., 2012; Akcali et al., 2010). But, empirical approaches only required the historical landslide data and associate rainfall data. The commonly investigated rainfall parameters to define empirical rainfall thresholds include cumulative rainfall, rainfall intensity, rainfall duration and antecedent rainfall.

The current landslide early warning system of Sri Lanka is based on the concept of hourly and daily rainfall intensities proposed by Bandara (2008) and it is being currently applied in regional extent commonly for all landslide-prone Districts. However, according to the past landslide incidents, the effect of rainfall for the initiation of landslides highly differs Locally in the Country and thus, the development of Local-level thresholds will be of immense help to improve the accuracy of the current early warning system. The present study is focused on defining threshold values for landslides in the Kalu River basin with the use of the empirical relationship of previously occurred landslides and associated hourly rainfall.

2. Materials and Methodology

2.1. Study area

The study focused on the Kalu River basin which is known as the second-largest basin in Sri Lanka. The basin covers about 2,766 km^2 and much of the catchment is located in the Rathnapura and Kalutara Districts which encountered a high frequency of landslides during the South West monsoon. The river basin lies entirely within the wet zone of the Country and the average annual rainfall in the basin is 4,040 mm with ranging from 6,000 mm in mountainous areas and 2,000 mm in the low plain (Ampitiyawatta and Shenglian, 2009).

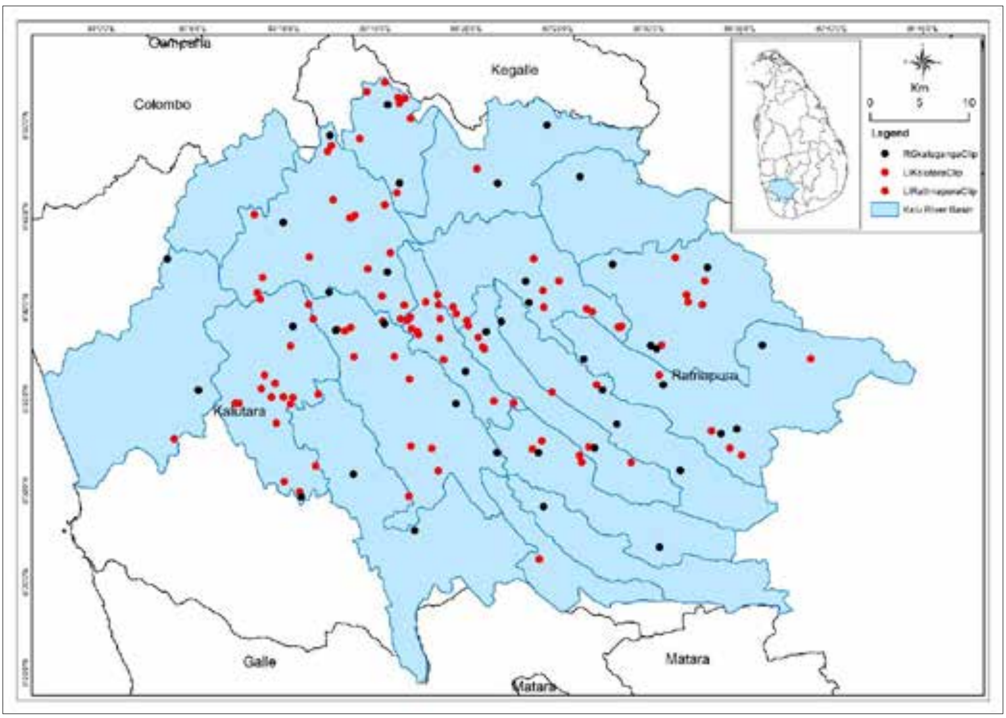


Figure 01: Map showing the Kalu Ganga basin, location of landslides (occurred after 1990) and rain gauge

2.2. Input data

To define the rainfall thresholds, historical landslide (except rock falls) data such as location, date and time of the occurrence from over 104 landslides that occurred within the basin between the years 1984 and 2020 were collected. Data were collected mainly from previous investigation reports of NBRO and the 'DesInventar database' of Disaster Management Centre (DMC).

Rainfall data were collected only from the automated rain gauge network of the NBRO because the analysis required hourly rainfall associated with landslides. The most effective rain gauges for the extracted landslides were selected by considering the distance to the landslide and morphology of the area by analyzing the spatial distribution of landslide locations and rain gauge stations using GIS. It is assumed that the rainfall value of the selected effective rain gauge sufficiently represents the condition at the location of the respective landslide.

Almost all the collected landslides did not have the exact occurrence date and time and instead only the year, month and day of the occurrence. On the other hand, almost all the effective rain gauges did not have rainfall records for a significant period. Finally, 37 disaster records that occurred after 2015 had to be shortlisted and utilized for the analysis and rainfall records had to be limited only to 10 automated gauging stations.

2.3. Method of analysis

Depending on the combinations of frequently used rainfall parameters, several empirical thresholds and graphs have been developed by researchers. One of the commonly used graphs correlates the total amount of rainfall until landslide occurrence (critical cumulative rainfall) with the maximum recorded intensity (hourly rainfall). This study was also focused to correlate the critical cumulative rainfall and hourly rainfall with the landslide occurrence.

The first step of the assessment of the rainfall threshold is to identify the rainfall episodes or triggering rainfall event which causes the occurrence of the landslides. For that, rainfall time series graphs were drawn for rainfall records at each rain gauge station (Figure 2a and 2b). Then analyzed the rainfall sequence for each landslide event and isolate the triggering rainfall based on expert judgement.

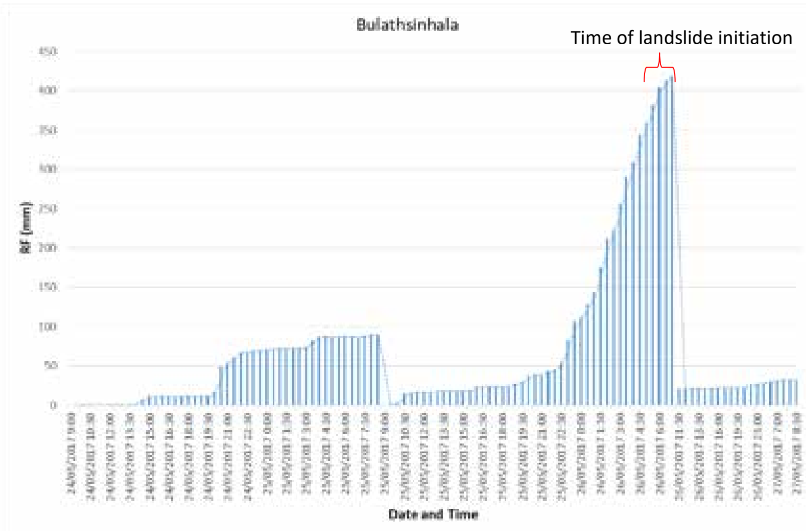
Then, hourly and cumulative rainfall requirement for the initiation of each landslide was established by back-calculation of the available 30 minutes rainfall records at 10 rain gauging stations and then plotting the graphs of hourly and cumulative rainfall against the respective time series (Figure 3a and 3b).

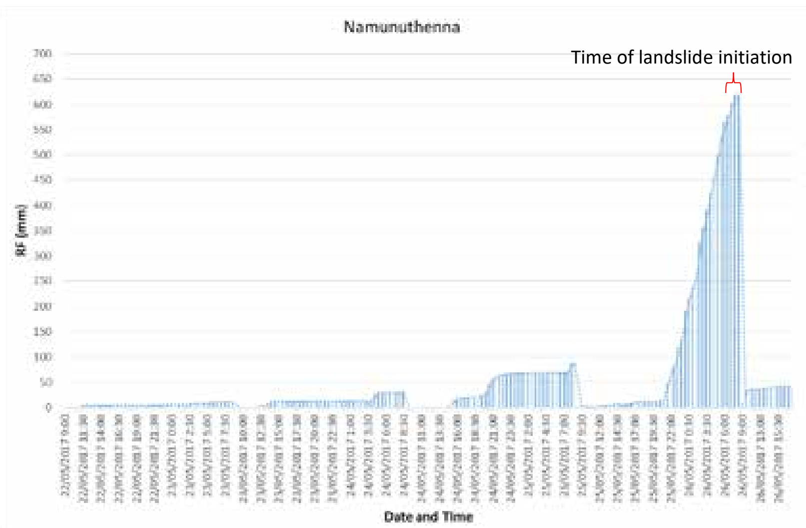
Then, points of past landslide events were plotted on each graph to determine the lowest cumulative rainfall value responsible for initiate landslides at each location.

3. Result and discussion

When considering the rainfall episodes that triggered landslides, two Distinct rainfall situations that trigger landslide events can be identified. Since graphs obtained for all 10 rain gauging stations can be categorized under the two situations, only a few significant graphs were selected to discuss the characteristics of rainfall events and landslide occurrences.

According to the rainfall time series graphs in Figure 2a, some landslides were initiated by intense rainfall that occurred in 2 - 4 hour time duration followed by a maximum of 3 - day cumulative rainfall. In consideration of the total amount of cumulative rainfall at the point of initiation of those landslides, it varies from 260 mm to 510 mm (Figure 3a and Table 1).





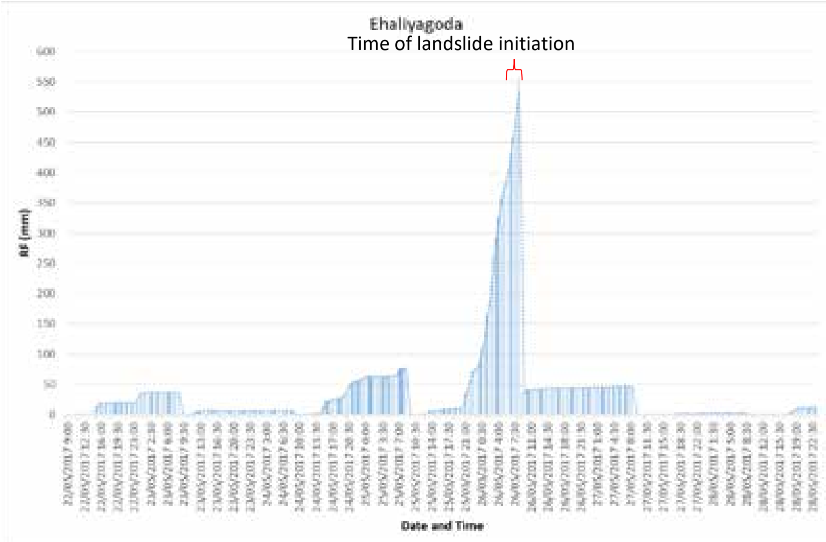
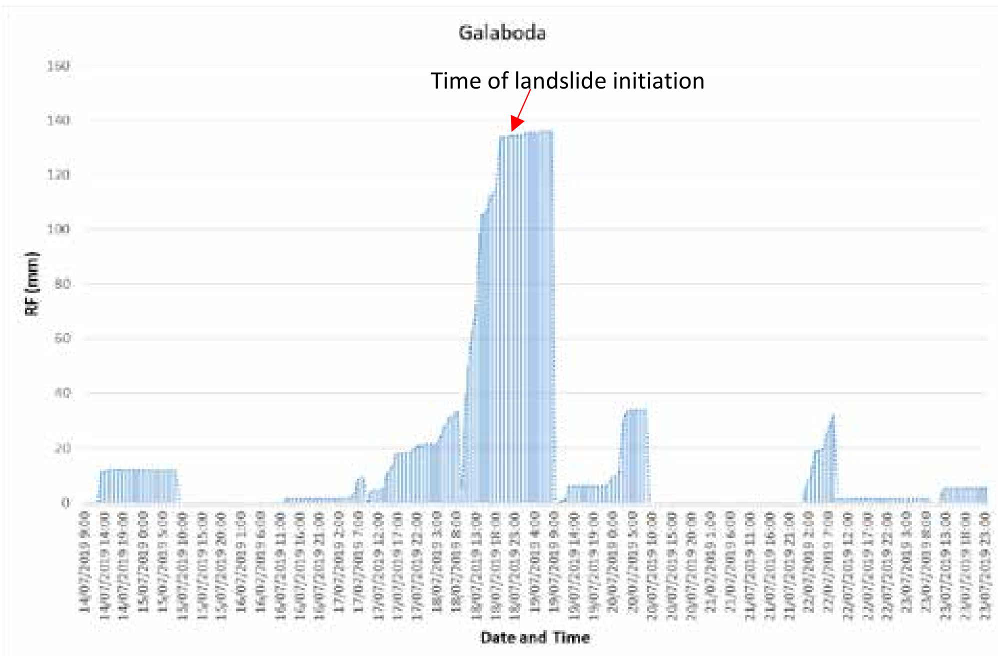


Figure 2a: Rainfall-Time series graphs of Kalu River basin

According to Figure 2b, some landslides were initiated with sudden rainfall that occurred within a day and the total cumulative rainfall required to initiate those landslides varies roughly from 155 mm - 185 mm (Figure 3b and Table 1). Further, according to the field details, these are already unstable areas accompanied by soil cuts or ground cracks before the landslide occurrence.



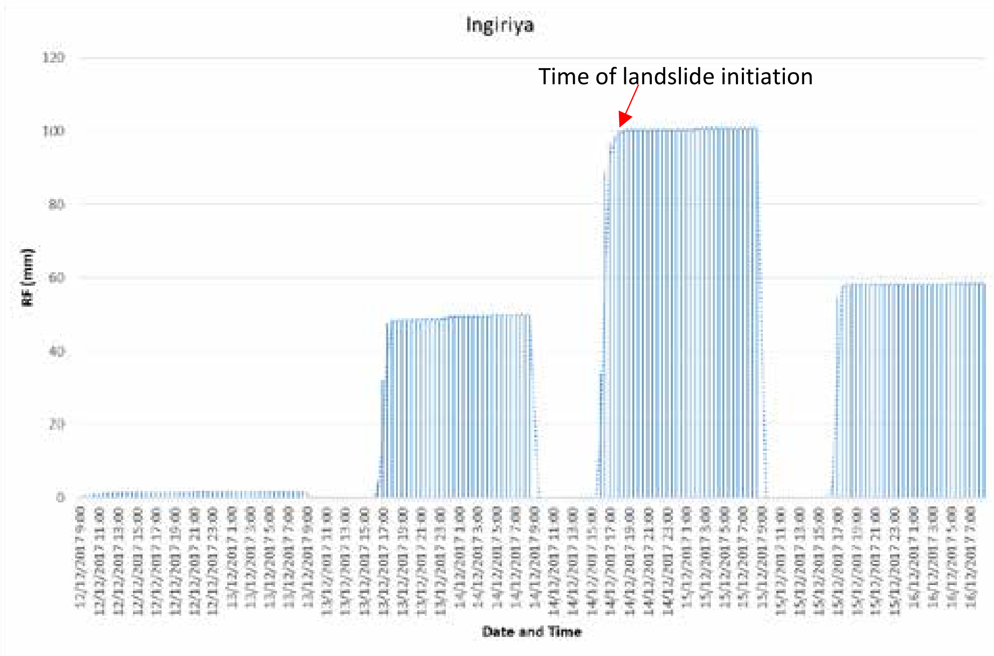


Figure 2b: Rainfall-Time series graphs of Kalu River basin

Rainfall plays an important roll in initiation of landslides by means of water infiltration into the subsoil which causes an increase in pore pressure value and thus, decrease in soil shear strength (Nafarzadegan et al., 2013). But, the influence of rainfall for the landslide initiation is difficult to quantify as water infitraion is depends on permeability properties of the soil (Aleotti, 2004). Moreover, a given threshold varies in space and time with changing landslide - Controlling factors, for example, vegetation, geology, soils and topography (Crozier and Preston, 1998). Therefore, it can be suggests that the local variations of the obtained rainfall threshold resulted due to the place to place variation of these controlling factors.

On the otherhand, presence of already unstable area can facilitate the rapid water infiltration into the slope mantle causing rapid increase in pore water pressure. In such situation landslides could be trigger even in comparatively low cumulative rainfall.

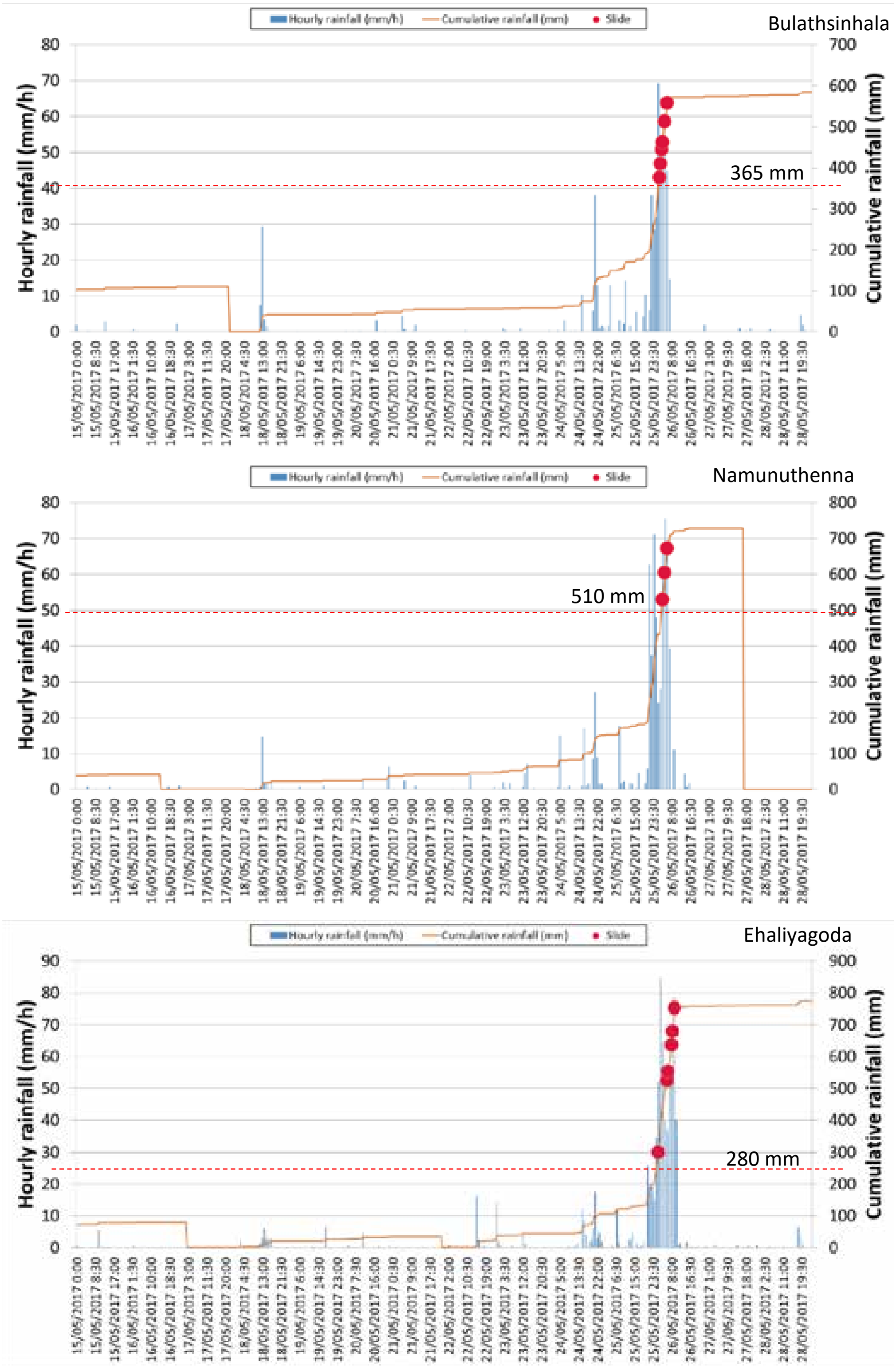


Figure 3a: Cumulative rainfall values correspond to the initiation of landslides

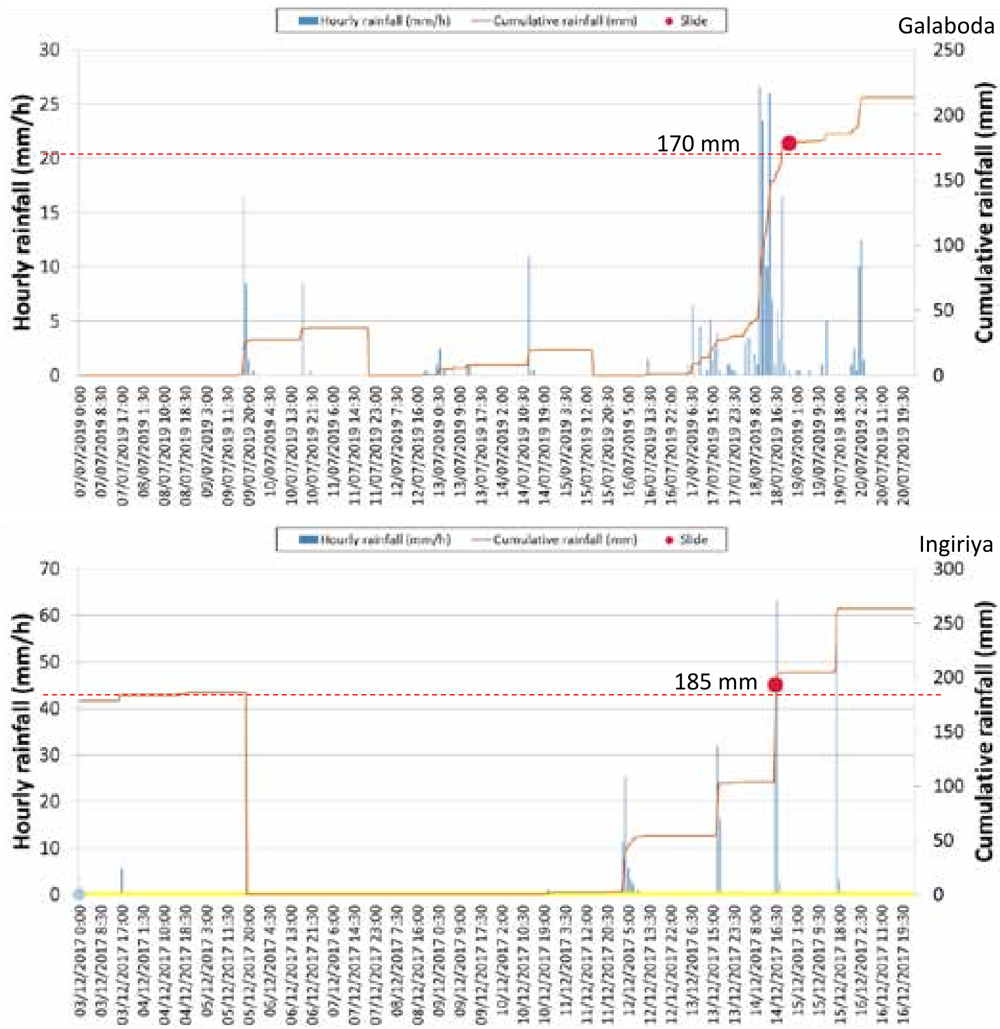


Figure 3b: Cumulative rainfall values correspond to the initiation of landslides

The red horizontal lines in Figure 3a and 3b are critical rainfall lines based on visual analysis of the rainfall graphs.

According to the obtained results, 89% of the analyzed landslides in the study area were initiated with 2 - 4 hour intense rainfall which was followed by cumulative rainfall effect for a maximum of 3 days and the rest of 11% of landslides were initiated with suddern rainfall event with relatively low cumulative value.

On the other hand, that 89% of landslides were initiated when cumulative rainfall is greater than 260 mm, but hourly rainfall widely ranges from 25 mm to 130 mm. The rest of 11% of the studied landslides were initiated when cumulative rainfall is lower than 190 mm with hourly rainfall exceeding 70 mm. The result indicated that intense short term rainfalls together with unstable slopes cause landslides even with relatively lower cumulative rainfall ranges from 155 mm to 185 mm.

Table 01. Hourly rainfall and cumulative rainfall values at the initiation of landslides

Rain gauge station	Hourly rainfall at the initiation of a landslide	Minimum cumulative rainfall at the initiation of a landslide
Bulathsinhala	50 mm - 70 mm	365 mm
Namunuthenna	60 mm - 70 mm	510 mm
Ehaliyagoda	35 mm - 70 mm	280 mm
Baduraliya	50 mm - 60 mm	265 mm
Endane	25 mm - 35 mm	300 mm
Wewelwaththa	65 mm	335 mm
Rathnapura	130 mm	410 mm
Galaboda	< 5 mm	170 mm
Ingiriya	80 mm	185 mm
Pelmadulla	70 mm	155 mm

Considering all these facts, the critical line for the study area can be set as in the Figure 04 based on visual analysis. In this case landslide at Galaboda is consider as a outlier and negrected for the estimation of the critical line Based on the critical line, the hourly rainfall requirement to initiate a landslides in the study area becomes lower by increase of cumulative rainfall.

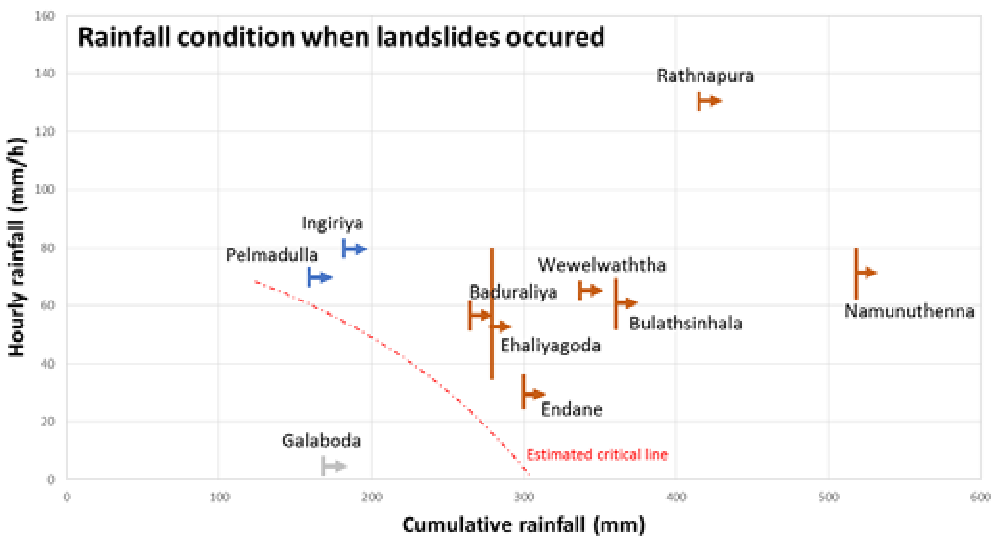


Figure 04: Rainfall condition when landslides occured

4. Conclusion and reccommendations

According to the obtained results, most of the landslides in the study area were initiated with the presence of 2 - 4 hour intense rainfall followed by maximum 3 days cumulative rainfall grater than 260 mm But in these landslides hourly rainfall widely ranges from 25 mm to 130 mm.

In few locations where the slope is already unstabilize by slope cut, ground crack etc. landslides were initiated with suddern rainfall event with relatively low cumulative value grater than 155 mm and less than 190 mm and hourly rainfall exceeding 70 mm indicating that intense short term rainfalls together with unstable slopes cause landslides even with relatively lower cumulative rainfall.

However, based on all the type of landslide initiation, it can be concluded that the hourly rainfall requirement to initiate a landslides in the study area becomes lower by increase of cumulative rainfall. But, as these different features in different scale more research is suggested to investigate the relationship between rainfall and other physical characteristics to trigger a landslide event.

5. References

1) Akcali, E., Arman, H., Firat, S., Saltabas, L., & Gunduz, Z. (2010). Rainfall thresholds for the initiation of landslides in Trabzon province of Turkey. International Journal of Engineering & Applied Sciences, 2(4), 14-26.
2) Aleotti, P. (2004). A warning system for rainfall-induced shallow failures. Engineering Geology, 73(3-4), 247-265.
3) Ampitiyawatta, A.D. & Guo, S. (2009). Precipitation trends in the Kalu Ganga basin in Sri Lanka. The Journal of Agricultural Science, 4(1), 10-17
4) Bandara, R. M. S. (2008, October). Landslide early warning in Sri Lanka. In Regional seminar on experience of geotechnical investigations and mitigation for landslides, Bangkok, Thailand (pp. 13-14).
5) Berti, M., Martina, M. L. V., Franceschini, S., Pignone, S., Simoni, A., & Pizziolo, M. (2012). Probabilistic rainfall thresholds for landslide occurrence using a Bayesian approach. Journal of Geophysical Research: Earth Surface, 117(F4).
6) Bhattacharjee, S., Ray, P. C., Chattoraj, S. L., & Dhara, M. (2017). Precipitation intensity: Duration based threshold analysis for initiation of landslides in upper Alaknanda valley. International Journal of Environmental Chemical Ecological Geological and Geophysical Engineering, 11(2), 105-109.
7) Kumara, G.D.D., Jayathissa, H.A.G. and Nawagamuwa, U.P., (2018). Determination of Rainfall Thresholds for Landslides in Sri Lanka. 9th annual symposium on innovation for build back better, National Building Research Organisation, pp.55-63.
8) Nafarzadegan, A. R., Talebi, A., Malekinezhad, H., & Emami, N. (2013). Antecedent rainfall thresholds for the triggering of deep-seated landslides (Case study: Chaharmahal & Bakhtiari province, Iran). Ecopersia, 1(1), 23-39.

9) Rao, K.S. and Singh, T. (2015). Rainfall Thresholds for Landslides: Their Capabilities and Limitations. Journal of Engineering Geology/Proceeding of EGNM 2015.
10) THIEBES, B., Shibiao, B. A. I., Yanan, X. I., GLADE, T., & Rainer, B. E. L. L. (2017). Combining landslide susceptibility maps and rainfall thresholds using a matrix approach. Revista de Geomorfologie, 19(1), 58-74.
11) White, I.D., Mottershead, D.N. & Harrison J.J. (1996). Environmental systems, 2nd ed. London, Chapman and Hall, (pp. 616).
12) Wieczorek, G. F. (1996). Landslides: investigation and mitigation. Chapter 4-Landslide triggering mechanisms. Transportation Research Board Special Report, (247).

The Assessment of Potential Damage Area for Debris Flows Using Landslide Hazard Zonation Map and Yellow Zone and Red Zone Methodology in Kalugala Micro-Catchment in Kegalle District, Sri Lanka.

SSADK Fernando[1], WMIGTS Senevirathne[1], PMGR Bandara[1], MDSS Karunaratne[1]

[1]Geologist, National Building Research Organization, Sri Lanka.

Abstract

Landslides are one of the major geological hazards in Sri Lanka's hilly Regions, posing a considerable threat to life and property. Landslide hazard zonation maps illustrate the level of susceptibility in a given area, although they are only useful for identifying landslide prone areas, not debris transport or deposition zones. One of the most widely used approaches for locating impact zones due to mass movement is the yellow zone and red zone methodology for debris flow. These zones were demarcating the areas of debris flow paths. A red zone is defined as an area where landslides are likely to cause serious damage to buildings and people. The term "yellow zone" refers to an area that is vulnerable to landslide.

According to this analysis, mass release from the high-susceptible area can almost follow the interpreted flow path downstream. As a result, the damages to buildings and other properties can be predicted ahead of time.

Kalugala micro-catchment, located west of the Aranayake micro-catchment, was chosen as the study area. The interpretation was based on the comparison of the community spreading factor and the land use component. The flow path has flowed in a westward direction, according to the interpretation. The yellow zone encompassed over 0.44 km2, whereas the red zone covered nearly 0.42 km^2. The precision of the contours and the location of the control points may have an impact on the outcome. Because natural processes are difficult to predict, 100% accuracy cannot be achieved from this strategy. But, conducting field verifications with experts may leads to resolving the many inequalities.

Keywords: landslide, flow path Interpretation, yellow/red zone methodology, LiDAR data, plan curvature

1. Introduction

Landslides are a major geological hazard in Sri Lanka's hilly Regions, posing a considerable threat to life and property. The National Building Research Organisation (NBRO), which has been recognized as the Country's National focal point for landslide risk management, has made significant efforts to reduce landslide risk through a variety of approaches, including but not limited to landslide susceptibility mapping.

NBRO has prepared landslide susceptibility maps for all landslide-prone locations of the Country as part of the Landslide Hazard Zonation Mapping Project (LHZMP). These maps' hazard levels, on the other hand, are just an indication of the potential of a landslide initiation at a certain location. As a result, it's only useful for identifying landslide rupture zones, not debris transport channels or deposition zones.

The most destructive landslides in Sri Lanka have been heavy rain-induced abrupt events with extensive run-out distances and rapid run-out velocities, which give no time for those living in down stream impact zones to safely evacuate due to their unexpected nature. As a result, developing site-specific hazard maps that demarcate all impact zones is critical for lowering the likelihood of future sediment disasters in Sri Lanka.

As a result, yellow zone and red zone (Y/R zone) debris flow techniques, which are a Japanese methodology, can be used to solve this problem. It demarcates potential debris flow paths, as well as high and low risk zones designated as red zone and yellow zone, respectively.

2. Study area

According to the 6,106 and 6,010 numbered landslide hazard maps (1:10,000) created by NBRO, the Kalugala area has been identified as a high hazard zone, and there has been an identified already occurred landslide (Aranayake landslide). Kalugala micro-catchment was belongs to Kegalle District in Sabaragamuwa Province. This location was chosen because a high-hazard zone has already been designated above the populous Region, intense rainfall, steep slopes, irregular land use and deforestation.

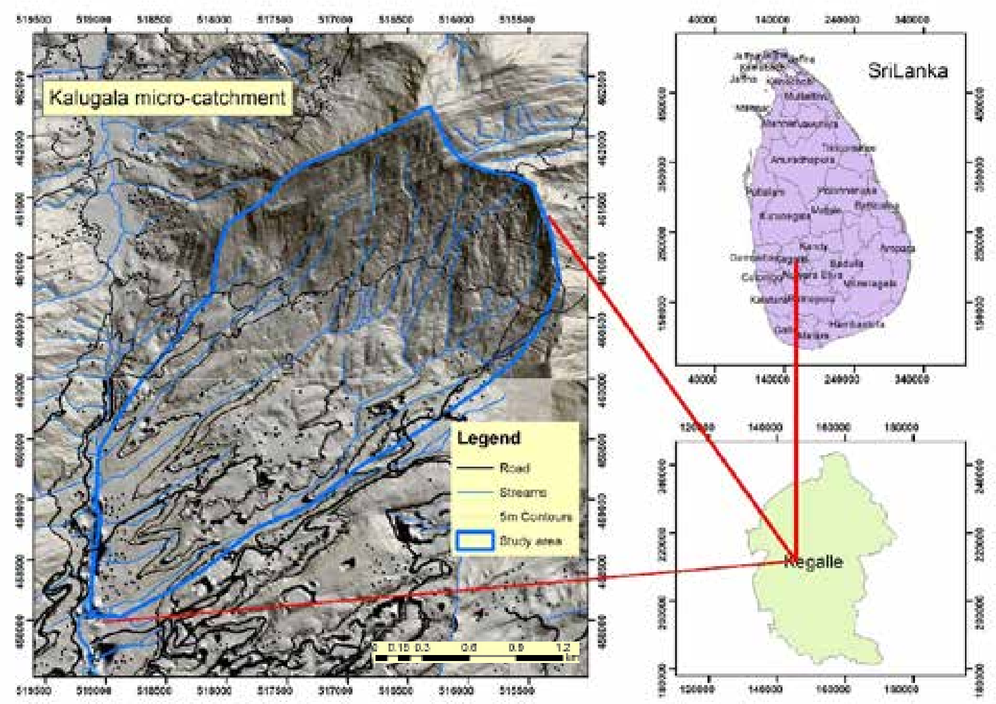


Figure 01: Geographical location of the Kalugala micro catchment

3. Methodology

3.1 Landslide hazard zonation map

A landslide hazard zonation map is a tool for determining the level of hazard in a given location. Geology map which indicates lithology data and structural data, overburden and landslide map which indicate type and depth of overburden and already occurred landslide data, hydrology map which indicate surface drainage data, slope map which indicate changes in elevation on a highly detailed level, land use map, and landform map which indicate geomorphology in an area, are the six - factor maps used to create it.

First, all six - factor maps were weighted based on the weighting methodology. Then weighted factor maps were overlayed and categorize to susceptibility zones to produce the final Landslide hazard map. Then already occurred landslide data layer, rock fall layer which include the prone areas of rockfall and stream layer add to the final map.

Desk studies such as rock outcrop digitizing, stereoscopic air photo analysis for geological structures, geological structures digitizing, field map, fishnet, avenza map, digital navigation system preparation were done to pre-determine the morphological, topographical and structural features of the mapping area. It was done by using air photos, Google Earth and ArcGIS software.

To design the geology map and the overburden and landslide map necessary field data were collected. Field maps were used to make a note of the required data.

Table 01: Field data for Geology map and overburden map

Geology map	Overburden map
Foliation	Soil type
Joints and intensities	Soil thickness
Rock type	Landslides
Structures	Cutting failures
Certain and uncertain contacts	Rock falls
Weathering stage	Rock outcrops

Geology and overburden data were collected and displayed independently on two maps. Data was also placed into an excel sheet. In the field, potential landslide cutting failure/ slope failure areas were identified, as well as cutting failure/ landslide locations that had already happened. After the field data has been finalized, geological features and layers can be plotted. Using stereoscopic analysis, those identifications were validated. After the geology and overburden maps were completed, they were expected to be digitized. Following that, the weighting process was used to weight all six - factor maps. The final landslide hazard zonation map was created by overlaying weighted factor maps and categorizing them into susceptibility zones. After that the resulting map is enhanced with an already occurred landslide data, possible rock fall data, and a stream layer.

3.2. Yellow and red zone identification procedure

The following steps are used to set the "Yellow Zone" and "Red Zone" for both slope collapse and debris flow. Selection of target area, preparation survey for the target area, setting of yellow zone and red zone and field verification to finalize the zones.

3.2.1. Y/ R zone for slope failure

3.2.1.1. Selection of Target Area

The target area, which includes the "Initial area," is chosen using NBRO's Landslide Hazard Zonation Map (LHZM) at a scale of 1 : 10,000. The current land use plans and social factors such as population, public places which are proportionally related with the magnitude of the destruction are also taken into account when choosing a target location. Topographical factors, social conditions, and slope unit are all taken into account while choosing a target Region. This technology can be used on both natural and artificially cut slopes.

Considering the topographical conditions, the target area shall be a steep soil slope having a gradient between 25 and 50 degrees and a height of 5 m. As social conditions, the target area should include residential area on which at least one residential house or public building is located. Areas which have no houses at present, but may be expected to be developed for housing or public building construction later based on the social conditions such as current land use and development plans should be also considered. Also, the areas where there is no possibility of residential house construction are excluded from target area selection. Cutting slopes along road are excluded from target area selection because such slopes have been managed by other administration authority. Regarding the slope unit in the case of laterally continuous steep slope, the area should be sectioned up to approximately 500 m in length based on topographical or administrative factor.

3.2.1.2. Preparation Surveys for the Target Area

A survey of previous disaster records for the target area is conducted to assess the extent of previous debris flows and their damage conditions, and then to obtain data such as; date, time, location, cause of a debris flow disaster, size of debris flow, damage to humans, damage to houses (type and degree), and rainfall information for hazard zone area setting.

Artificial constructions such as; walls, retaining walls, pitching works, embankment, excavation, drainage channel, ditch and others should be checked if they exist in the target region.

3.2.1.3. Setting of Y/ R zone

First step is to set of traverse lines and preparing of cross sections. The traverse line should be set to the highest slope angle possible. In order to account for topographical altering points and artificial structures, the traverse line should be spaced at around 20 m intervals along contours. After that, each traverse line's cross section must be prepared. Then to set of upper edge when examining upslope on cross section of each traverse line, the upper edge shall be identified primarily at the topographical change point where a continuous upper slope has a gradient of less than 25 degrees or more than 50 degrees. Next to set of lower edge when examining downslope on a cross section of each traverse line, the lower edge shall be established at the topographical change point where a continuous lower slope has a gradient of less than 25 degrees or more than 50 degrees. Slope height is measured as relative height between the lower and upper. The left and right margins are determined by the following criteria: slope boundary where the slope height is less than 5 m, slope boundary where the slope angle is less than 25 degrees and more than 50 degrees, mountain stream boundary, and clear mountain ridge boundary. The steep soil slope area is set by straight lines connecting of all upper and lower. To set of red zone; a Region within the height of the steep slope from the bottom of a steep soil slope area (an area with a gradient between 25 and 50 degrees and a height of more than 5 m) and an area within the height of the steep slope from the bottom of a steep soil slope area. To set of yellow zone; An area located within a horizontal length of 10 m from the upper edge of a steep soil slope area; and an area located within twice the height of the steep soil slope area (if this exceeds 100 m, the limit is 100 m) from the bottom (or lower edge) of a steep slope area. Moreover, a section of the area that is clearly visible as not being within the reach of the collapsed sediment due to topographical features or structural obstacles such as embankments, excavations, channels, rivers, walls, retaining walls, and other structures should be properly modified and then excluded from the yellow and/or red zones.

3.2.1.4. Field Survey to Finalize the Y/ R Zones

During the field survey the topographical conditions of the area, lower and upper margins of the driven zones, slope angle and height, left and right edges, and manmade constructions, will be investigated regards to the target area. If the field survey reveals that the target region has a slope height of over 100 meters and is made up of fresh firm rocks with few fissures, it should be excluded from the hazard zones.

3.2.2. Y/ R zone for debris flow

3.2.2.1. Selection of target area

Areas that may be harmed by debris flows, as well as mountain streams where debris flows may occur. The target region is determined using a Hazard Zonation Map created by NBRO at a scale of 1:10,000, which depicts locations vulnerable to sediment disasters such as debris flow and slop failure.

The target area is chosen based on topographical and socio economic factors. Topographical conditions are taken into account to determine whether the target location has the potential for debris flow, such as the presence of a zero-stage valley and a debris fan landform. To comprehend the risk of debris flow damage in the target Region, such as residential residences, public buildings, roadways and so on, the social factors are taken into account.

3.2.2.2. Preparation survey for the target valley

A survey of previous disaster records for the target area is conducted to assess the extent of previous debris flows and their damage conditions, and then to obtain data such as date; time, location, cause of a debris flow disaster, size of debris flow, damage to humans, damage to houses (type and degree) and rainfall information for hazard zone area setting. To select the target area, evaluate the number of houses and public buildings in the region. If there is at least one house or public building in a residential area, it is considered a target area.

3.2.2.3. Setting of Y/ R zone

The setting of the Y/R Zone for debris flow is based on topographical interpretation and field survey.

According to the methodology the control point is determined as, outlet of the valley, upstream of house location, top of a fan landform, spot of gradient change, or outlet of a narrow stream. From this point the debris flow direction is basically determined to be perpendicular to contour lines around the valley landform in view of the straight-flowing nature of a large - scale debris flow. The gradient between the control point and the most downstream point of the debris flow considered as the ground gradient of the target area. The cross-sections are set to be perpendicular to debris flow direction at an interval of about 20 m starting from the control point. In addition, the length of the cross-section should be drawn from the current streambed to the relative height of about 10 m. Relative height about 5 m is set from the current streambed or the center of flow direction into both bank sides. Then boundary point at each cross-section is set. When the relative height between the streambed and the stream bank slope is less than 5 m, the boundary point at each section is determined based on the spreading angle of debris flow below the upper boundary points, 30° for Yellow Zone and 15° for Red Zone for one side. Next the downstream endpoint for the Yellow and Red Zones are determined based on the above-mentioned ground gradient measurement to be 1° for Yellow Zone and 3° for Red Zone.

3.2.2.4. Field verification to finalize the Y/R zones

Ground gradient, cross-section profile, planar shape, and artificial structures are all examined in the field to complete the zones. Furthermore, an area that is clearly confirmed outside the reach of debris flow due to its topographical qualities is excluded from the Yellow or Red Zones based on the field study.

4. Results and Discussions

Following methodology below interpretations were done.

The mass release from the high-risk location can practically follow this pattern downstream. As a result, the damages to buildings and other properties can be predicted ahead of time. The red zone, according to this technique, contains rock boulders, trees,

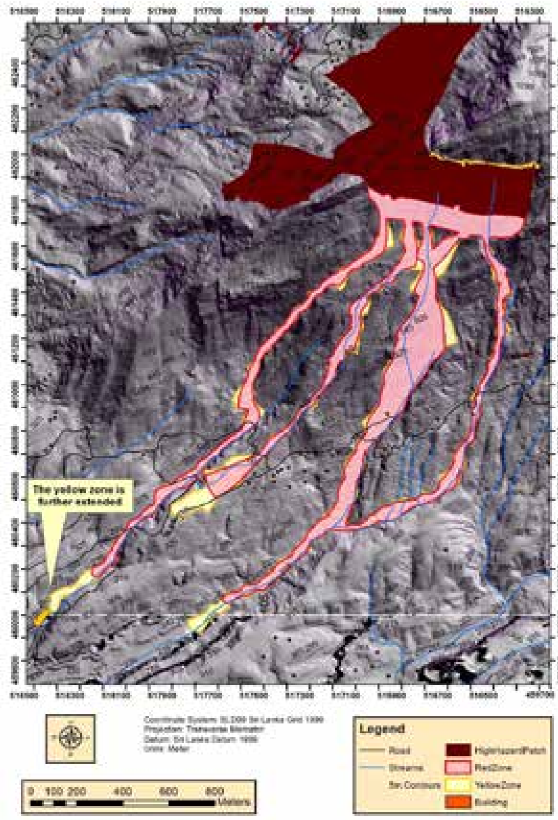


Figure 02: Interpreted Y/R Zone debris flow paths from the high-risk area

and any other debris that could cause structural damage. The yellow zone contains mud and other debris that is unlikely to cause structural harm. The interpretation was based on the comparison of the community spreading factor and the land use component. The initiation slope failure was sectioned using plan curvature and a high hazard patch. It aided in the correct prediction of the flow path.

Because the mass could discharge as a slope failure, the slope failure approach was applied for the interpretation. An upper yellow zone and a lower red zone were established. The Y/R zone for debris flow approach was used to evaluate the red zone debris flow patterns. The bulk that had been released was pushed into valleys and flowed downstream almost in the same direction as these paths.

According to the interpretation, the flow path has been flowing westward. The yellow zone was 0.44 km^2 in size, while the red zone was roughly 0.42 km^2. The yellow zone red zone debris flow method was used to increase the yellow zone in the bottom left corner of Figure 02 It's possible, however, that it won't be stretched as far in real life. There are no homes or properties along the flow channel that would be harmed if the flow path was widened.

This result may depend on the accuracy of contours and the control point locations. If a debris flow occurred the number of buildings, roads and other properties that may destroy can be determined by adding the corresponding layers of this area. Also, these interpretations can be used to done a proper land use management.

5. Conclusions and recommendations

In steep areas, landslides are a major geological hazard that poses a substantial threat to people and their property. As a result, precise assessments of the debris flow disaster may help to mitigate a significant amount of damage while also pointing the way to better land use management and future development plans. The road network may be disrupted as a result of debris flow disasters. As a result, these interpretations were critical in the construction of highways in a specific area. The Y/ R zone methodology for debris flow is a useful tool for determining the path of debris flow before a landslide occurs. However, there are some discrepancies between the yellow zone and red zone outcomes and the real result. Deviations can be minimized by doing field verifications.

6. References

1. Ibsen, M. L. and Brunsden, D.: 1996, The nature, use and problems of historical archives for the temporal occurrence of landslides, with specific reference to the south coast of Britain, Ventnor, Isle of Wight, Geomorphology 15, 241–258
2. Asmar, B.N., Langston, P.A., and Ergenzinger, P. (2003) the potential of the discrete element method to simulate debris flow. In: D. Rickenmann and C-L. Chen (eds), Debris-flow Hazards Mitigation: Mechanics Prediction and Assessment (Vol. 1, pp. 435–445). Millpress, Rotterdam.
3. Bear, J. (1972) Dynamics of Fluids in Porous Media (764 pp.). Dover, New York
4. NBRO User Manual (1995), Landslide Hazard Mapping in Sri Lanka, Landslide Hazard Mapping Project SRL89/001.
5. Manual for Site-Specific Landslide Hazard Zoning, project SABO, July 2020

Soil Water Index as a Determining Factor for Initiation of Landslides and Issuing of Landslide Early Warning in Sri Lanka

RMSAK Rathnayake[1], T Wada[2], HAG Jayathissa[1], KPGW Senadeera[1], MSM Aroos[1], DML Bandara[1]

[1]Landslide Research & Risk Management Division, National Building Research Organisation, Sri Lanka

[2]Earth System Science Corporation Limited., Japan

Abstract

Severe rainfall is a major trigger of landslide in Sri Lanka. Rainfall increases soil water content causing landslides. Thus, the National Building Research Organisation (NBRO) issues national landslide early warnings for the central mountainous areas mainly based on 24 hour rainfall. Aiming to improve the accuracy of the landslide early warnings, this study reviewed challenges of the existing operational National landslide early warning mechanism in Sri Lanka and analyzed its practical results over the past years to clarify thresholds and critical lines for the warnings.

Based on the results of landslide, rainfall correlation analysis in 2014 - 2021, the 48 hour and 72 hour cumulative rainfall are the causing factors for initiating the landslide and it varies with the considerable margin. The long term rainfall strongly affects the landslide early warning process in Sri Lanka because the 48 hour and 72 hour cumulative rainfall shows stronger correlation with the landslides than 24 hour rainfall.

Furthermore, analysis on the Soil Water Index (SWI) was conducted at 19 sites located in the landslide - prone Districts to reinforce consideration of the effects of antecedent rainfall and to determine warning thresholds for landslides considering Regional variation. The SWI is a rainfall index calculated by using the tank model and indicating variation of soil water content and increase of landslide risks. The parameter set of the tank model was validated by the past observed rainfall and river discharge in Sri Lankan mountainous condition by a previous study. Based on the analysis results, landslide effective soil water index, 24 hour, 48 hour, 72 hour values were above 140 SWI, 150 mm/24 h (in cases of less antecedent rainfall), 175 mm/48 h and 220 mm/72 h, respectively. Especially, the Aranayake landslide was triggered 185 SWI even though

the 24 hour rainfall was 140 mm. It suggests that SWI seems to contribute to improve accuracy of landslide early warning.

It is recommended to further develop and improve landslide early warning system considering SWI and the other long term rainfall indices. Overall, improvement of input rainfall data accuracy, regular revision of tank model parameters, and relevant adjustment of landslide warning issuing levels were suggested to improve the efficiency of the national landslide forecast system.

Keywords: landslide early warning, landslide-rainfall correlation, soil water index

1. Introduction

Landslides, slope failures, debris flows and other sediment-related disasters cause severe social and human damages in Sri Lanka. Heavy tropical rainfall is a cause of infiltration and soil saturation, and triggers many landslides in the mountainous region located in the center of Sri Lanka. As the result, ca. 35% of death and missing by disasters were caused by landslides and other sediment disasters in Sri Lanka in the decade from 2007 to 2016 (JICA, 2016). Therefore, prediction of landslide occurrence is important to reduce the disaster damages.

In Sri Lanka, National Building Research Organisation (NBRO) issues landslide early warnings based on the observations of real time rainfall. There are previous studies (Bandara, 2008; Rathnayake, 2015; Kumara et al., 2018; Rajapaksha et al., 2019; Wada et al., 2021) on landslide warning thresholds. The landslides in Sri Lanka are mostly triggered by severe rainfall in the two inter-monsoon periods in May and October - December. According to the previous studies, various rainfall thresholds to issue landslide early warnings were proposed. At present, NBRO issues landslide early warnings mainly based on 24 - hour rainfall (75 mm/24 h: watch, 100 mm/24 h: alert, 150mm/24h: evacuate) considering the empirical correlation between rainfall amount and landslide occurrence (Bandara, 2008). However, “air-shot” and “miss-shot” of landslide warnings occurred in the actual warning operation. Therefore, further studies aiming to improve the accuracy of the landslide early warnings are required for precise predicting in minimizing the loss of human lives. This study reviewed challenges of the existing operational national landslide early warning in Sri Lanka and analyzed correlation between rainfall indices and landslide occurrence over the past years to clarify proper thresholds and critical lines for the warnings.

NBRO currently utilize 24-hour rainfall for landslide early warning, but it is concerned that effects of remaining soil water fed by antecedent rainfall are inadequately considered for the warning. The SWI, which is utilized for landslide early warning in Japan, represents characteristics of soil water behavior and is able to reflect the antecedent rainfall effects. Thus, this study focused on the SWI and examine application of SWI as well as 24-hour to 72 hour rainfall indices for landslide early warnings.

2. Methodology

2.1. Study area and data for analysis

The target area of this study is 14 landslide-prone Districts located in the mountainous Central Region in Sri Lanka. NBRO installed nearly 300 automated rain gauges in the area and conduct continuous rainfall observation since 2014. In addition, NBRO reports and archives all landslide information collected by field surveys. These rainfall time series data and landslide reports from 2014 to 2021 were utilized on the analysis for this study.

2.2. Data analysis

An empirical method was applied to analyze the correlation between landslide occurrence and triggering rainfall by using time series data of rainfall indices and the landslide records. The time series of the rainfall indices and its momentary value triggering landslides were calculated and plotted on charts to clarify rainfall thresholds causing landslides.

Time series of 24 hour, 48 hour and 72 hour rainfall during the landslide events were calculated by using the recorded rainfall data at every 30 minute time slots. Moreover, Soil Water Index (SWI) which is utilized for landslide early warning in Japan was also calculated using the 30 minute rainfall.

SWI was developed by Okada et al; (2001). The tank model, a conceptual runoff model developed by Sugawara, (1972) was utilized to calculate the SWI. The tank model, consisting of surface, sub-surface and base flow tanks, simulates amount of water in soil layers and discharge (Fig. 1). The formula of SWI is as follows:

$$SWI = S_1 + S_2 + S_3$$
$$S_1(t+\Delta t) = (1-\beta_1\Delta t).S_1(t) - q_1(t).\Delta t + R$$
$$S_2(t+\Delta t) = (1-\beta_2\Delta t).S_2(t) - q_2(t).\Delta t + \beta_1.S_1(t).\Delta t$$
$$S_3(t+\Delta t) = (1-\beta_3\Delta t).S_3(t) - q_3(t).\Delta t + \beta_2.S_2(t).\Delta t$$
$$q_1(t) = \alpha_1[S_1(t)-L_1] + \alpha_2[S_1(t)-L_2]$$
$$q_2(t) = \alpha_3[S_2(t)-L_3]$$
$$q_3(t) = \alpha_4[S_3(t)-L_4]$$

where, S_1, S_2, S_3 ; Water amount in the tank (mm), β_1, β_2, β_3 ; Infiltration rate, q_1, q_2, q_3 ; Discharge (mm/Δt), Δt ; Time step, R ; rainfall (mm/Δt), α_1, α_2, α_3, α_4 ; Runoff ratio, L_1, L_2, L_3, L_4 ; Height of runoff hole (mm). 10 - minute time step (Δt) is utilized on this analysis. SWI is calculated as the total amount of simulated water in the tanks (S_1+ S_2+ S_3) at each time step. The parameters of the tank model were proposed by Ishihara and Kobatake (1979) through runoff analysis in the pilot mountainous basins in Japan. These parameters were validated in Sri Lankan conditions by Gamage et al; (2021). SWI and discharge during past severe events in Sri Lankan basins were calculated by Gamage et al. (2021) by using the tank model parameters including infiltration and runoff ratio and compared/validated with observed discharge. The result shows that the parameters proposed by Ishihara and Kobatake (1979) can be applicable for the Sri Lankan basins. According to the study of Gamage et al; (2021), the parameter sets were utilized in this study. The SWI is summation of the latest rainfall as well as remaining soil water fed by antecedent rainfall minus discharge and deep percolation. Thus, the SWI includes the effects of antecedent rainfall better than 24 - hours rainfall.

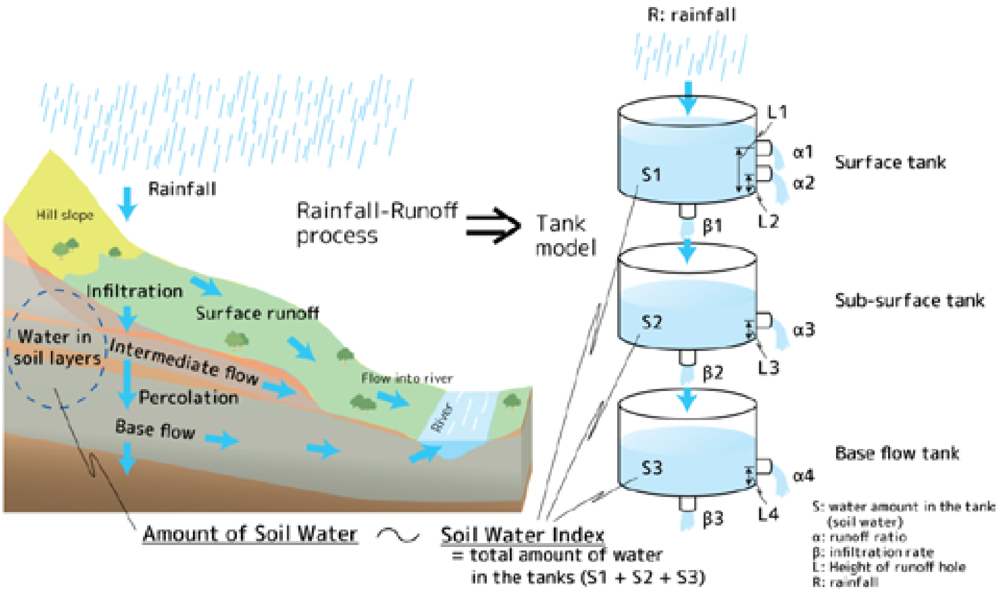


Figure 01: Structure of tank model (Wada et al., 2021)

Landslide records were also utilized for the analysis. Location and time of past landslides were extracted from the NBRO landslide reports (Fig. 2). Finally, 19 landslide records and time series of 24 h, 48 h, 72 h rainfall and SWI at rain gauges located near the landslides were utilized for the analysis.

The time series of the calculated rainfall indices and those instantaneous values when landslides occurred were plotted on the time series charts. Furthermore, "snake curve charts" (scatter line chart with X-axis : SWI as long term rainfall index and Y-axis : hourly rainfall as short term rainfall) with probability contour of rainfall occurrence which is estimated by using log-normal probability distribution were calculated. Finally, the characteristics and thresholds of the rainfall triggering landslides were examined.

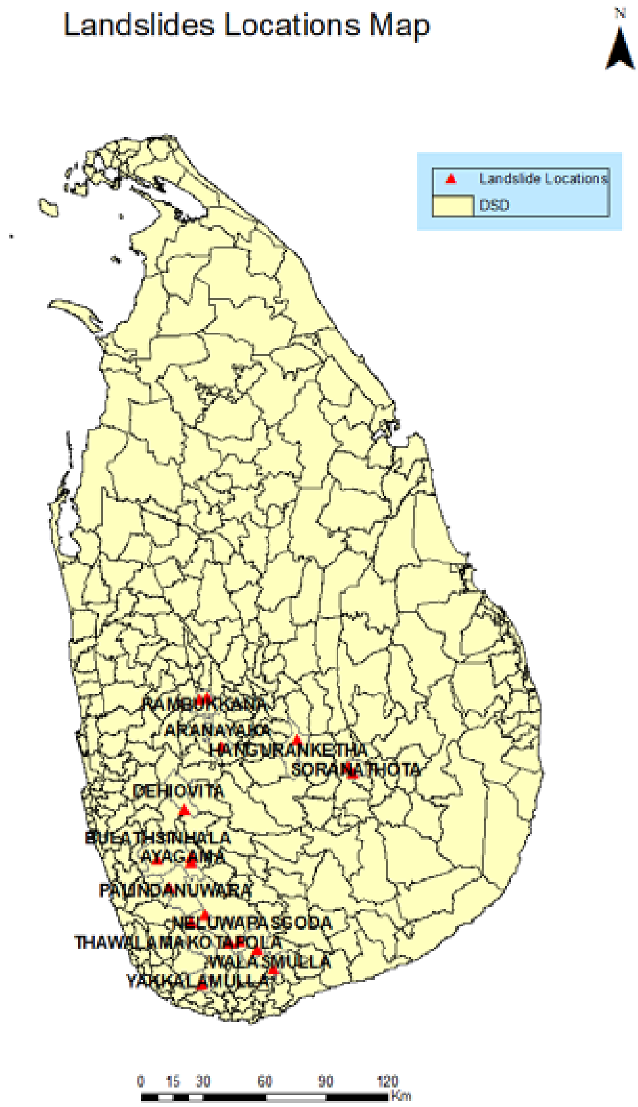


Figure 02: Locations of landslides

3. Results and Discussion

3.1. Results of analysis

Analysis results of the representative four landsides are shown as follows. Fig 3 shows SWI, 24 hour rainfall and hourly rainfall at Aranayake landslide event in 2016. The continuous rainfall was started at 7.00 on 15th May 2016 and caused a huge landslide at around 16.30 on 17th May 2016. The SWI and 48 hour rainfall reached 185 and 315 mm, respectively, when the landslide occurred. However, 24 hour rainfall was 140 mm which was less than the evacuation warning threshold (150 mm). Fig 4 shows snake curve charts of SWI, 24-hour rainfall and hourly rainfall with probability contour lines of rainfall occurrence. The SWI when the Aranayake landslide occurred was almost at the peak. On the other hand, the 24-hour rainfall decreased from the peak.

The Aranayake landslide is a representative case of large antecedent rainfall effect and deep-seated landslide. The SWI and 48 hour rainfall were similar to the other landslides (Table 1), but 24-hour rainfall was less. It suggests that the effects of remaining soil water and infiltration to the deeper layer were underestimated by 24-hour rainfall, but the high SWI and 48 hour rainfall indicated the risk of landslide occurrence.

Figure 5 shows SWI, 24-hour rainfall and hourly rainfall of Ayagama landslide event in 2017. This landslide was caused by a concentrated rainfall event compared with the

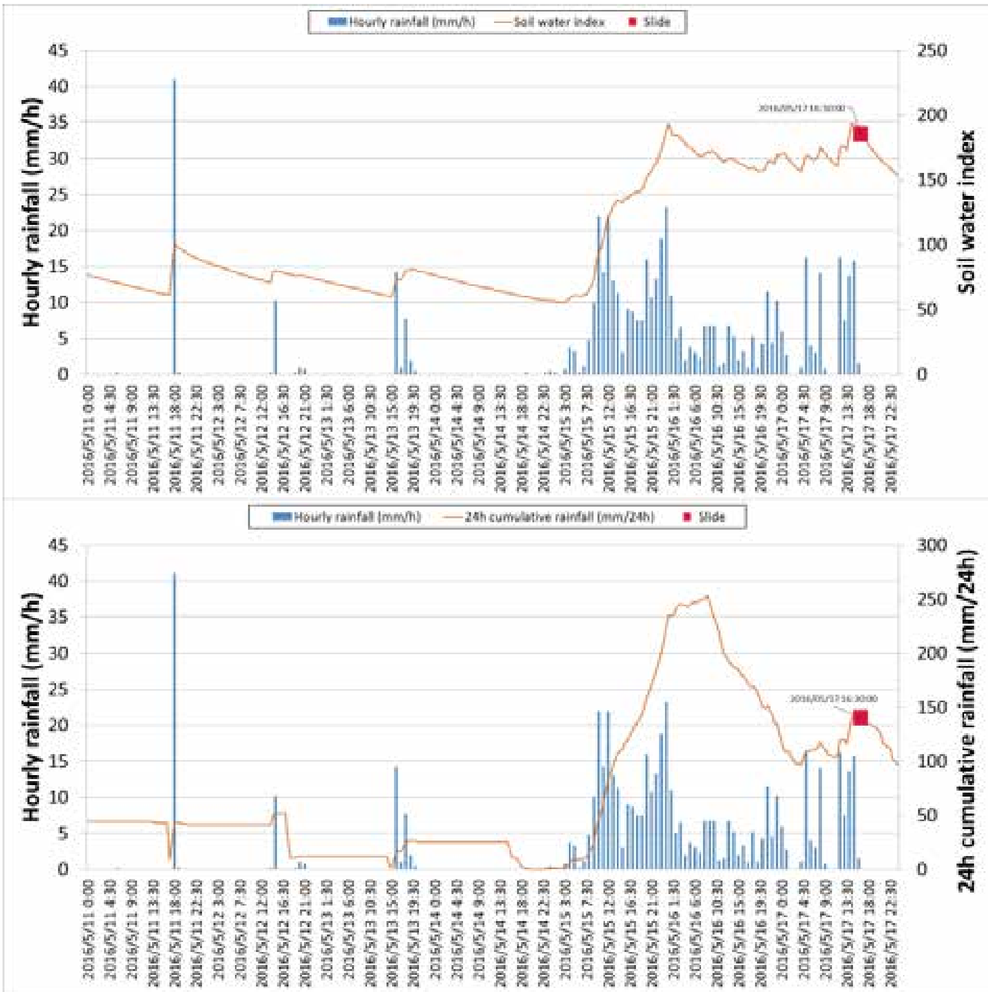


Figure 03: SWI (upper), 24 hour rainfall (lower) and hourly rainfall for the Aranayeke landslide in 2016

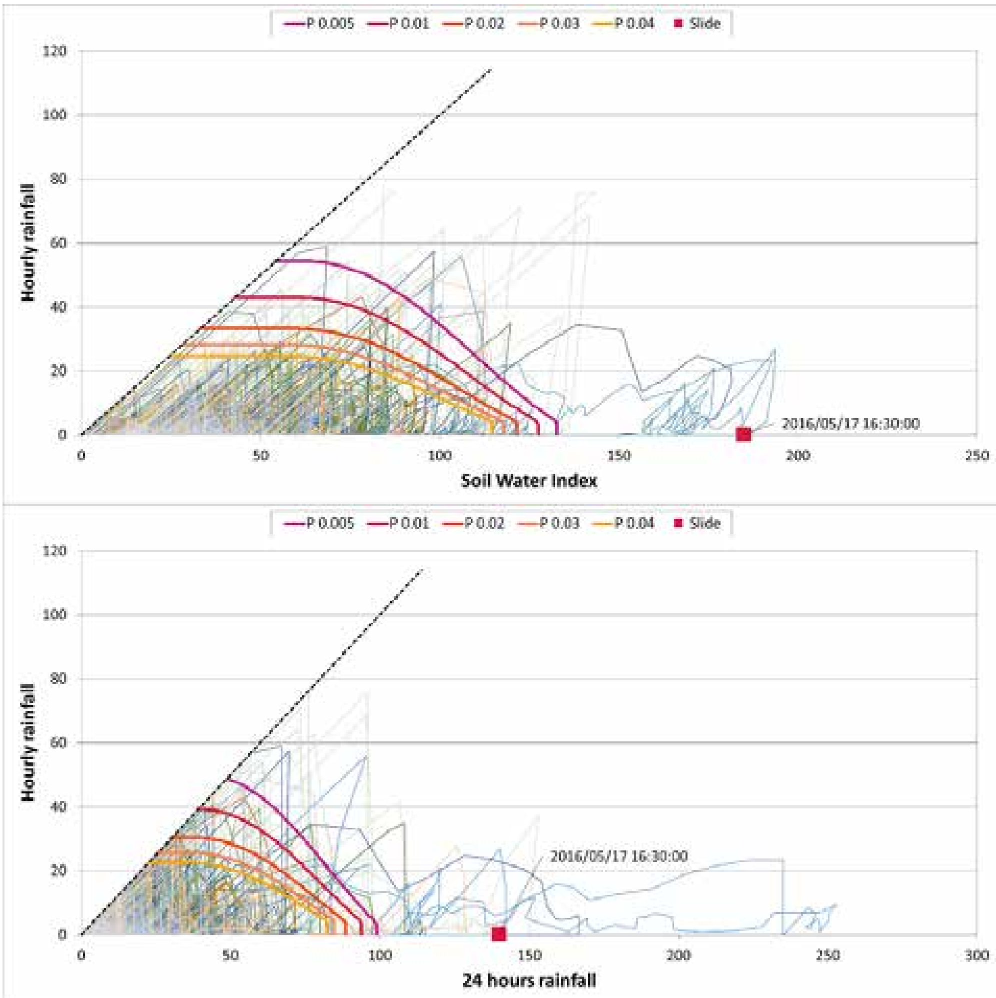


Figure 04: Snake curve charts of SWI (upper), 24 hour rainfall (lower) and hourly rainfall with probability contour lines of rainfall occurrence

Aranayake landslide. Ca. 30 mm/h - 70 mm/h rainfall continued around a half day and caused a landslide at around 4.00 on 26th May 2017. The SWI and 48 hour rainfall reached 294 and 463 mm, respectively, when the landslide occurred. 24 hour rainfall was also high (377 mm) which exceeded the evacuation warning threshold (150 mm). In the case of the concentrated and single rainfall event causing Ayagama landslide, SWI and 24 hour rainfall were both high and significant compared with the other landslides (Table 1).

Fig 6 shows SWI and hourly rainfall of Bulathsinhala landslide event in 2017. This landslide was also caused by a concentrated rainfall event. The heavy rainfall started at 20.00 on 24th May 2017 and caused the landslide at 3.10 on 26th May 2017. The SWI and 48 h rainfall reached 242 and 350 mm, respectively, when the landslide occurred. 24 h rainfall was also high (272 mm) which exceeded the evacuation warning threshold (150 mm). The SWI and 24 hour rainfall triggering the Bulathsinhala landslide were both similar to the other landslides caused by concentrated rainfall events (Table 1).

Fig 7 shows SWI and hourly rainfall of Dehiovita landslide event in 2018. This landslide was caused by a minor rainfall event one day after a main rainfall event. The main rainfall event was on 20th May 2018 with no landslides. The minor rainfall below 20 mm/h occurred at 14.00 on 21st May 2018 and caused Dehiovita landslide. The SWI and 48 h rainfall reached 140 and 241 mm, respectively, when the landslide occurred. 24h rainfall (161 mm) slightly exceeded the evacuation warning threshold (150 mm). The values of SWI and 24 hour rainfall causing the Dehiovita landslide under continuous rainfall condition were near to lower limit compared with the other landslides.

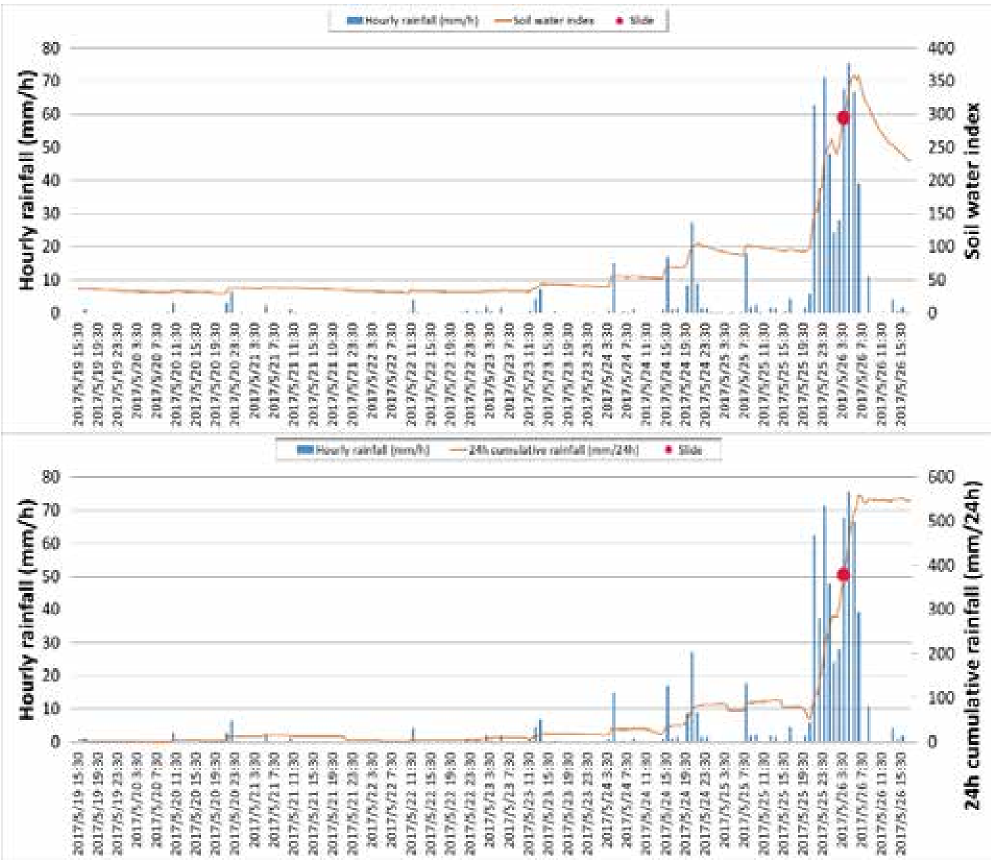


Figure 05: SWI (upper), 24 hour rainfall (lower) and hourly rainfall for the Ayagama landslide in 2017

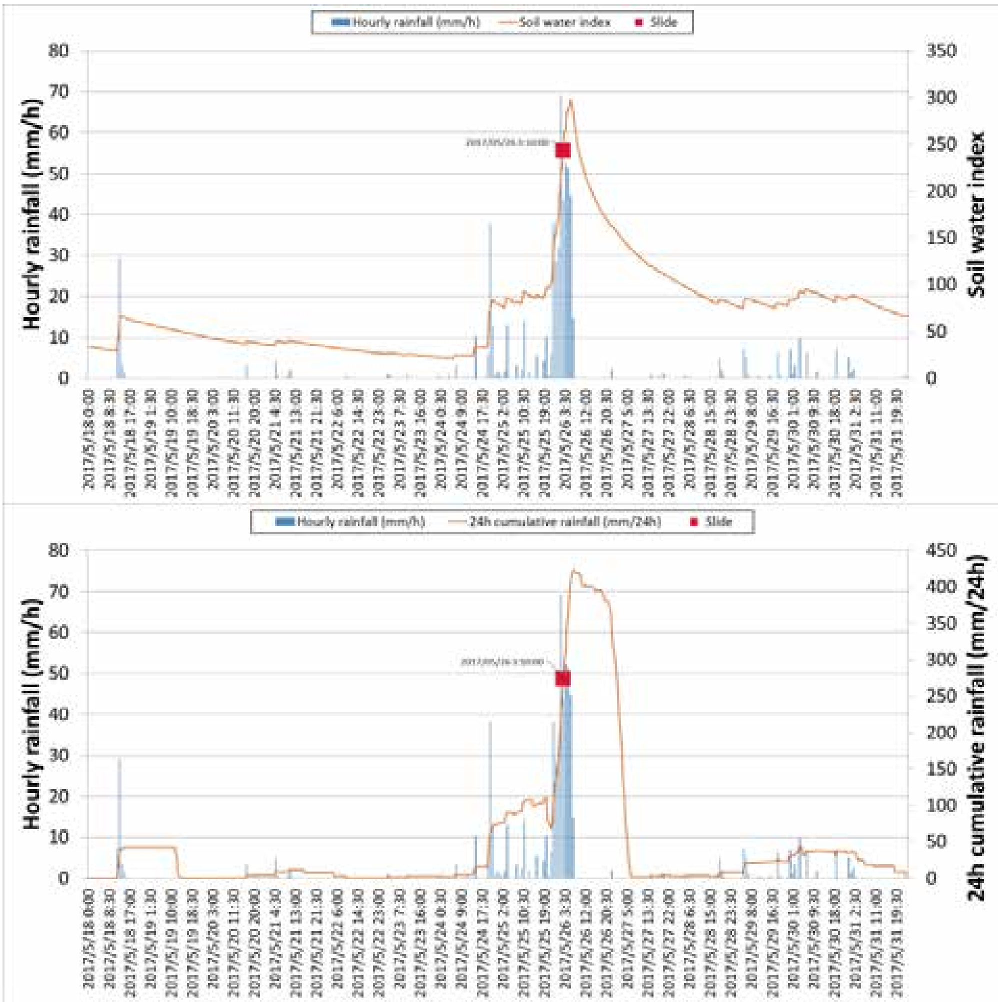


Figure 06: SWI (upper), 24 hour rainfall (lower) and hourly rainfall for the Bulathsinhala landslide in 2017

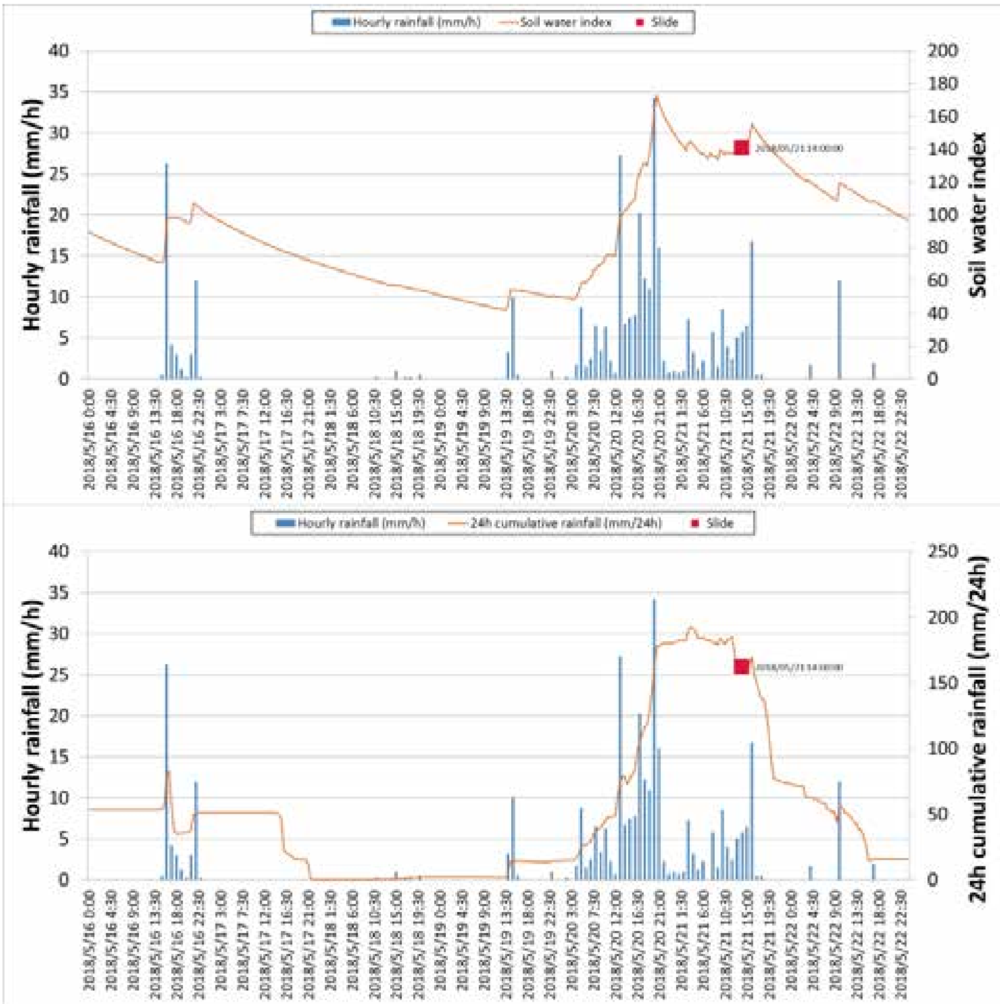


Figure 07: SWI (upper), 24 hour rainfall (lower) and hourly rainfall for the Dehiovita landslide in 2018

3.2. Discussion

According to the rainfall - landslide correlation analysis, the current evacuation warning thresholds (150 mm/24 h) caught the landslide occurrence in case of concentrated rainfall events. However, some landslides occurred below the current warning threshold in some case that landslides caused by continuous rainfall (Table 1).

Table 1 shows values of SWI and 24 hour, 48 hour and 72 hour rainfall at the past landslides. Seven landslides were caused when 24 h rainfall exceeded the current warning threshold, but two events occurred below the warning threshold. If the 24 hour rainfall threshold is lessened, all landslides can be caught. However, "air-shots" of landslide warnings must increase. Therefore, it is recommended to utilize 24 h rainfall as well as the other long-term rainfall indices (SWI and 48 h rainfall) which represent effects of continuous rainfall.

The deference between the 48 hour (mean 294 mm) and 72 hour (mean 324 mm) rainfall triggering the past landslides were smaller than the deference between the 24 hour (mean 205 mm) and 48 hour rainfall (Table 1). Thus, up to two days rainfall before landslides seems to be more important to predict landslides. Variances of SWI (190 ± 43, 23%) and 48 hour (294 ± 84, 29%) and 72 hour (324 ± 75, 23%) rainfall triggering the past landslides were smaller than 24 hour rainfall (205 ± 88, 43%) when landslides occurred (Table 1 and Fig. 8). It indicates that the thresholds of these long-term rainfall indices which trigger landslides can be determined more clearly. Fig. 8 shows correlation between SWI and 24 hour rainfall causing the past landslides. In the cases of relatively low antecedent rainfall (SWI ≤ 24 hour rainfall), the 24 hour rainfall triggering landslides and SWI are almost in a linear relationship. In contrast, in the cases of relatively high antecedent rainfall effect (SWI > 24 hour rainfall), the 24 hour rainfall fell below 150 mm, but SWI ranged still in high value between 140 - 190. It suggests that the SWI represents landslide risks caused by antecedent rainfall and catches the incidents. Based on the analysis results, landslide effective SWI, 24 hour, 48 hour, 72 hour values were above 140 SWI, 150 mm/24 h (in cases of less antecedent rainfall), 175 mm/48 h and 220 mm / 72 h, respectively.

Table 01: Values of Soil Water Index (SWI) and 24h, 48h and 72h rainfall at the past landslides

Nos	District	DSD	Landslide Location	Soil Water Index (SWI)	24 Hour Rainfall (mm)	48 Hour Rainfall (mm)	72 Hour Rainfall (mm)	Date and time of landslides
1	Kegalle	Aranayake	Samasiriya	185	140	315	440	5/17/2016 16:30
2	Rathnapura	Ayagama	Ayagama Town	294	377	463	479	5/26/2017 4:00
3	Kegalle	Dehiovita	Ambalanpitiya	140	161	241	246	5/21/2018 14:00
4	Kalutara	Bulathsinhala	Thibbotukanda	242	272	350	352	5/26/2017 3:10
5	Galle	Yakkalamulla	Yatamalagama	156	112	257	278	5/26/2017 0:30
6	Galle	Neluwa	Kosmulla	153	181	312	323	5/25/2017 0:40
7	Galle	Thawalama	Kumburegoda	235	258	392	403	5/25/2017 0:00
8	Matara	Kotapola	Morawaka	257	319	417	427	5/26/2017 7:15
9	Matara	Kotapola	Kotapola West	188	206	274	284	5/25/2017 22:30
10	Matara	Pasgoda	Pasgoda	191	328	342	343	5/25/2017 23:30
11	Hambantota	Walasmulla	Gamhewagoda	228	349	387	387	5/26/2017 0:00
12	Badulla	Soranathota	Soranathota	173	130	175	218	12/25/2014 22:00
13	Badulla	Soranathota	Moragoola	196	209	268	297	12/26/2014 7:00
14	Nuwara Eliya	Hanguran-ketha	Udawaththa	156	152	189	271	12/25/2014 9:30
15	Kegalle	Rambukkana	Kotawela	152	126	178	244	11/6/2021 2:00
16	Kegalle	Rambukkana	Kotawela	197	185	241	320	11/6/2021 5:00
17	Rathnapura	Ayagama	Ayagama	178	154	338	340	6/4/2021 6:30
18	Kalutara	Baduruliya	Baduruliya	150	173	234	234	6/4/2021 2:00
19	Rathnapura	Elapatha	Elapatha	137	61	209	273	6/5/2021 6.30
Minimum				137	61	175	218	
Average ± standard deviation				190±43	205±88	294±84	324±75	
Rate of standard deviation to average				23%	43%	29%	23%	

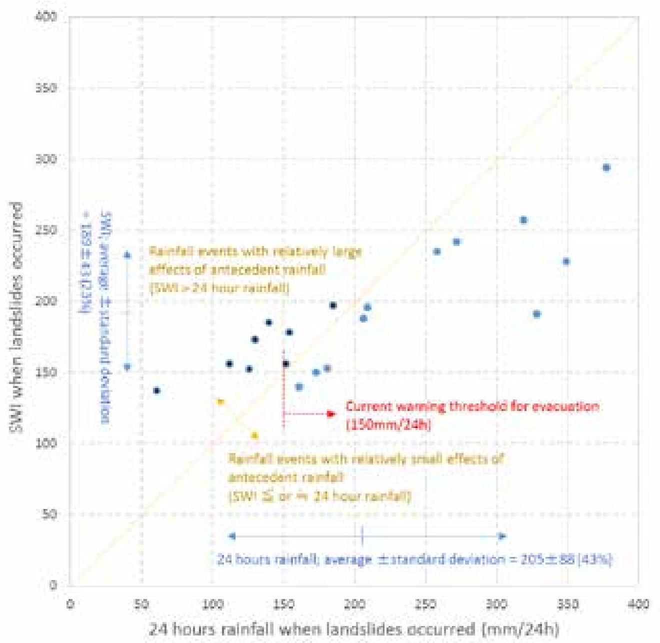


Figure 08: Correlation between SWI and 24 hour rainfall causing the past landslides

4. Conclusions

The thresholds of existing early warning system which NBRO use are 150 mm/24 h cumulative rainfall for the evacuation. However, five cases out of 19 cases show that landslides are triggered even if the rainfall is less than 150 mm/24 h. This analysis result indicates that most of the landslides are able to be caught by the current warning threshold, but it is recommended to update the warning thresholds to catch up the landslides caused by long-term rainfall.

According to the results, long term rainfall indices (48 - hours rainfall, 72 - hours rainfall and SWI) show stronger correlation to the landslide occurrence than 24 hours rainfall. Especially, SWI was more effective than 24-hour rainfall in the cases that antecedent rainfall was observed in the cases of Aranayake, Yakkalamulla, Dehiovita and Kotawella. It suggests that the increase of soil water by the long-term rainfall affects severely to start mass-movements. In other cases that one huge short rainfall event caused landslides after less rainfall period, 24-hour rainfall was significant index. In the view point of lifting of warnings, it seems that lifting of warnings becomes late in case to utilize the long-term rainfall indices as warning thresholds. In addition, a strong point of 24-hour rainfall is easy for local people to observe it. In the practical cases in Sri Lanka, local people measure the 24-hour rainfall through community based disaster risk reduction activities for evacuation. However, it is impossible to measure SWI directly at the local level and utilize for evacuation in communities. Therefore, it is recommended to combine the 24 h rainfall with the long-term rainfall indices for the warning thresholds in order to take advantage of both rainfall indices.

It is recommended to further develop and improve landslide early warning system considering SWI and the other long term rainfall indices as well as Regional condition including geology, meteorology, since the number of landslide cases and related rainfall time series data are limited for studies at this moment. Overall, improvement of input rainfall data accuracy, regular revision of tank model parameters, continuous data collection of actual landslides and relevant adjustment of landslide warning issuing levels were suggested to improve the efficiency of the National landslide forecast system.

Acknowledgement: This study is implemented as a part of JICA Project entitled "Project for Capacity Strengthening on Development of Non-structural Measures for Landslide Risk Reduction in Sri Lanka". We appreciate JICA's international support. Furthermore, NBRO, the implementation organization of the project, has provided a lot of support for this study. We thank NBRO for the assistance.

5. References

1. Bandara, R. M. S. (2008). Landslide early warning in Sri Lanka. In Regional seminar on experience of geotechnical investigations and mitigation for landslides, Bangkok, Thailand, 13-14
2. Gamage, H. G. C. P., Wada, T., Senadeera, K. P. G. W., Aroos, M. S. M., and Bandara, D. M. L. (2021). Rainfall Triggered Landslide Early Warning System Based on Soil Water Index. Multi-Hazard Early Warning and Disaster Risks, Springer, 529-542
3. Ishihara, Y., and Kobatake, S. (1979). Runoff model for flood forecasting. Bulletin of the Disaster Prevention Research Institute, Kyoto Univ., 29(1), 27-43.
4. JICA (2016). Data collection survey on disaster risk reduction sector in Sri Lanka: final report. JICA, (pp. 245)
5. Kumara, G., Jayathissa, H., Nawagamuwa, U. (2018). Determination of Rainfall Thresholds for Landslides in Sri Lanka. 9th annual symposium, National Building Research Organisation, 55-63
6. Okada, K., Makihara, Y., Shimpo, A., Nagata,K., Kunitsugu,M. and Saito, K. (2001). Soil Water Index. Tenki, 48, 349−356 (in Japanese).
7. Rajapaksha, W. D. G. D. T., Wada, T., Jayathissa, H. A. G., Priyankara, N. H. (2019). Determination of thresholds based on rainfall indices for the occurrence of landslides in Kalu Ganga basin, Sri Lanka. 10th annual symposium, National Building Research Organisation
8. Rathnayake,R.M.S.A.K. (2015). Determination of localized Rain Fall Thresholds for Landslide: A Case Study in Kaluthara District in Sri Lanka. 2015, annual symposium, National Building Research Organisation.
9. Sugawara, M. (1972). Rainfall–runoff analysis method. Kyoritsu Publishing. Tokyo, (in Japanese)
10. Wada, T., Gamage, H. G. C. P., Senadeera, K. P. G. W., Aroos, M. S. M., Bandara, D. M. L., Rajapaksha, W. D. G. D. T. and Rathnayake, R. M. S. A. K. (2021). Study on Landslide EarlyWarning by Using Rainfall Indices in Sri Lanka. Multi-Hazard Early Warning and Disaster Risks, Springer, 777-787

Accuracy Assessment of Flow Path of Debris Flow of Slope Failure Using Yellow Zone / Red Zone Concept: A Case Study of Aranayake Landslide in Kegalle District, Sri Lanka

MDSS Karunarathne[1], PMGR Bandara[1], HMTL Herath[1], HAG Jayathissa[2]

[1] Scientist, National Building Research Organization, Sri Lanka
[2] Act. Director, Landslide Research and Risk Management Division, National Building Research Organization, Sri Lanka

Abstract:

Sri Lanka is a tropical country prone to landslides caused by excessive rainfall, and landslides have become a common natural hazard in the Country's Central Highlands. The National Building Research Organisation (NBRO) has developed a mapping methodology to forecast landslide susceptibility zones of initiation for easier disaster management and mitigation. This landslide susceptibility map, also known as the landslide hazard zonation map, has successfully predicted slope failure type landslide initiation zones in Sri Lanka. However, it does not show the whole possible damage zone, including the run-out area. The total damage zone assessment map needs to be simplified, which can also be used by the Local community to identify the potential damage area. To overcome this gap and to assess the accuracy of predicting the damage zone of the highest susceptibility zones in the landslide susceptibility map, the yellow and red zone concepts were used in a case study of the Aranayake Landslide in Sri Lanka. The objective of this research is to assess the accuracy of the damage zone compared to the area of the already - occurred Aranayake landslide, which is derived using the yellow and red zone concept. The initiation zone for the pilot site was selected with the aid of areas that have indicated the highest susceptibility of landslide occurrences in the landslide hazard zonation map and plan curvature analyses, which indicate the prominent valleys and geomorphological features by the focal statistics algorithm. The yellow and red zone preparation for slope failure methodology was used to analyze the zone for failure start and supply mass to debris flow propagation type propagation over the slope of the event. The debris flow methodology of the yellow and red zone concepts was then performed to predict the flow path and depositional zone. The result of the total damage zone was compared with the actual landslide boundary to check the accuracy of the damage zone derived using the yellow and red zone concept. The result of the research indicated that the damage zone assessment predicted 77.89% of the area as true-positive from the actual boundary of the landslide. Therefore, this methodology can be applied to the potential landslides and landslide susceptibility maps to fulfill the current gap in the Aranayake micro catchment. However, the results highly depend on the resolution of the terrain data. Field verification with an expert is highly recommended before making decisions.

Keywords: ***Landslide; Slope failure; Debris flow; Yellow and red zone, Damage zone assessment***

1. Introduction

1.1. Background

Sri Lanka is frequently subjected to landslides and slope failures due to the high intense of rainfall, mainly in two monsoon periods (Department of Meteorology, 2019);

- North-East monsoon (December to February)
- South-West monsoon (May to September)

A landslide is one of the major types of disaster in the Central Highland terrains of Sri Lanka. Gradually, landslide-prone areas are increasing with human involvement, and it is reported as 20% to 30% of the total land area of Sri Lanka (Annual Report – Landslide Hazard Zonation Mapping Project, 2017). In terms of area, the landslide-prone area has extended from 13,000 km^2 to 19,500 km^2 in the last decade, spread over 14 Districts (Figure 01). In every landslide disaster, losses of lives and property are recorded due to the increase in landslide occurrences following improper human settlements and other human involvements.

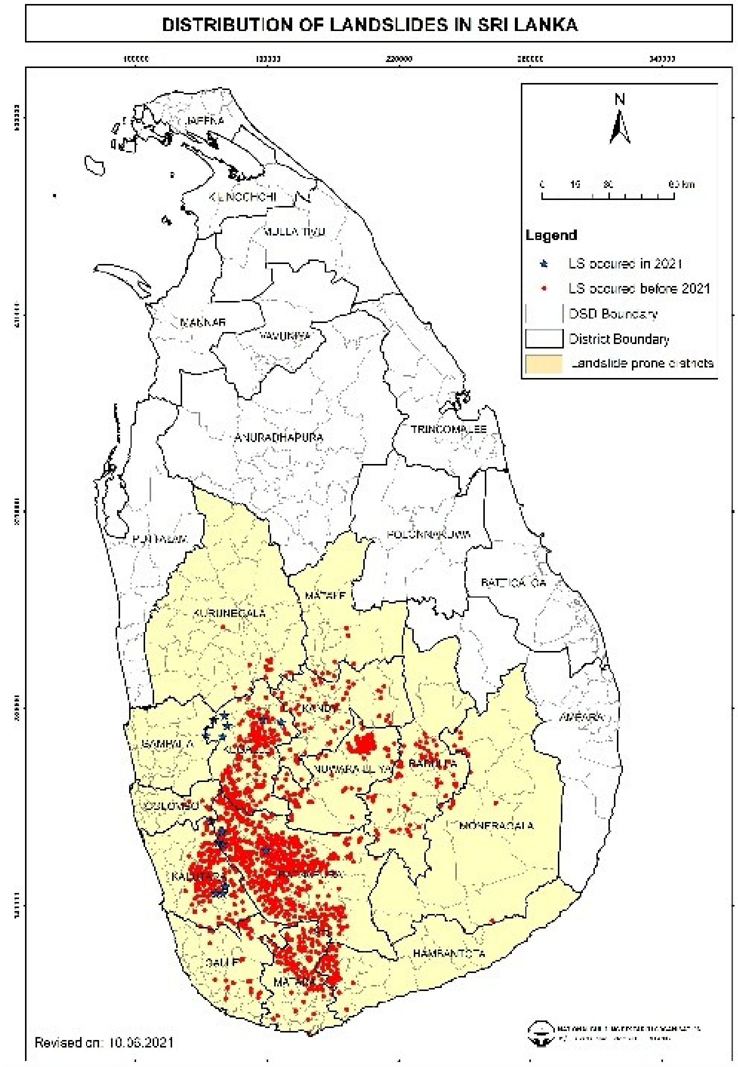


Figure 01: Distribution of Landslides in Sri Lanka (Source: National Building Research Organization)

1.2. Outline of Landslide Hazard Zonation Map

As a pre-disaster management strategy, the National Building Research Organisation (NBRO) has developed a method for indirectly predicting landslide initiation and the map is called "Landslide Hazard Zonation Map" (LHZM) under the Landslide Hazard Mapping Project (LHZMP) in 1:50,000, 1:10,000, and 1:5,000 scales with a considerable level of prediction power.

This method mainly considers the terrain factors, and it includes the weighting system for the terrain factors and sub-terrain factors, which have a function of landslide initiation (NBRO User Manual, 1995).

I Bedrock Geology and Geological Structure
II Type of Natural soil cover and Thickness
III Slope range and category
IV Hydrology and drainage
V Land use and management
VI Landform

These weightings are assigned by studying previous landslides and identifying the function of different terrain factors in the landslide initiation. Fieldwork is required to collect the necessary field data for weighting the terrain. Also, structural identification using air photo stereoscope analysis, field checking, and weighting for finalizing is required for the method of LHZM.

1.3. Yellow and Red Zone Concept

The Yellow and Red Zone (Y/R) concept is a Japanese zoning method of hazard level at a scale of 1:2,500 or 1:5,000 that is prepared to regulate or control new development for housing, promote the relocation of existing houses, and develop early warning systems for residents within landslide hazard zones. An area that is vulnerable to landslides can be designated as a "Yellow Zone." An area where there is a probability of serious risk of damage to buildings and houses and threats to residents from failures can be designated as a "Red Zone."

The Y/ R concept only focuses on three types of failure, including a) debris flow, b) slope failure and c) slide (Figure 02). Other failure phenomena are not predicted by this concept.

2. Study Area

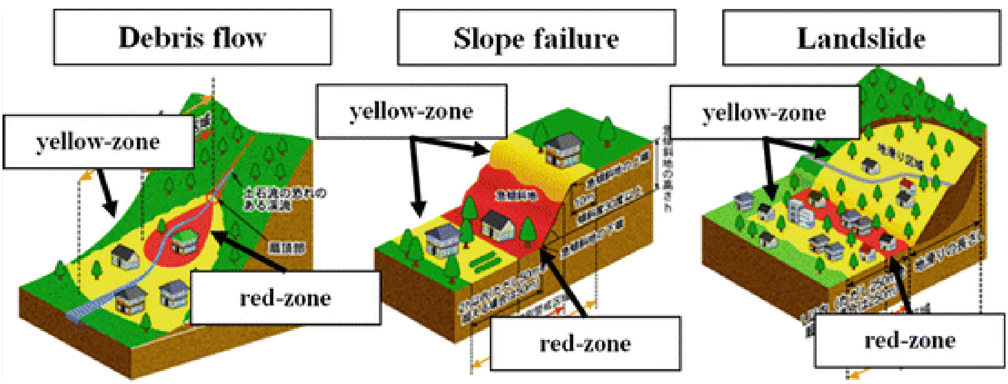


Figure 02: Failure types that predict from the Y/R concept (Source: Manual of Risk assessment for Yellow/Red zone)

The Aranayake landslide is a huge landslide with the initiating type of rapid slope failure due to high intensity rainfall and a sudden increase in pore pressure in the crown area that triggered the slope failure and then spread along the slope as a debris flow.

According to the Local community, this failure has occurred three times. Following the initiation of the slope failure, the first and second failures have flown down, filling the valleys and modifying the existing terrain. The third failure has spread following the modified terrain. With the high moisture content of debris, which acts as a semi-liquid, debris slows reaching the almost flat terrain following the modified morphology (Figure 03).

Aranayake landslide is one of the most disastrous events in Sri Lankan history losing hundred lives and damaging area of 523,626 m^2. The common details of Aranayake landslide are in table 1.

Table 01: Details of Aranayake Landslide

Province	Sabaragamuwa
District	Kegalle
Divisional Secretarial division (DSD)	Aranayake
GPS	7.154736 N, 80.430149 E
Date of Occurrence	17^{th} May, 2016
Time of Occurrence	4.30 pm
Initiation width	175 m
Initiation depth	10 m
Initiation length	243 m
Initiation Area	40,541.4 m^2
Damages	31 deaths / 96 missing
	523,626 m^2 damaged

Figure 03: Aranayake Landslide (Source: JICA Report)

3. Methodology

The initiation zone for the pilot site of Aranayake was selected based on the highest susceptibility zone, called the zone of "landslides are most likely to occur" by LHZM, and plan curvature analyses to identify the prominent valleys and geomorphological features using the focal statistics algorithm. The un disturbed terrain of the event was selected for the study since the damage area should be predicted beforehand. Then the Y/ R zone for slope failures was drawn following the methodology and analyzed the zone for failure start and supply the mass to debris flow type propagation (Figure 5). After that, debris flow methodology of the Y/ R zone concept was performed to predict the flow path and depositional zone. The steepest paths of the debris flow paths were drawn based on the steepest path and then considering the momentum of a semi-liquid material over a slope (Figure 5). Then the result of the total damage zone was compared with the actual landslide boundary to assess the accuracy of the damage zone derived using the Y/ R zone concept. For the comparison, the area percentage of the predicted damage zone by the result of the Y/ R zone concept to the actual landslide damage area was used (Figure 4).

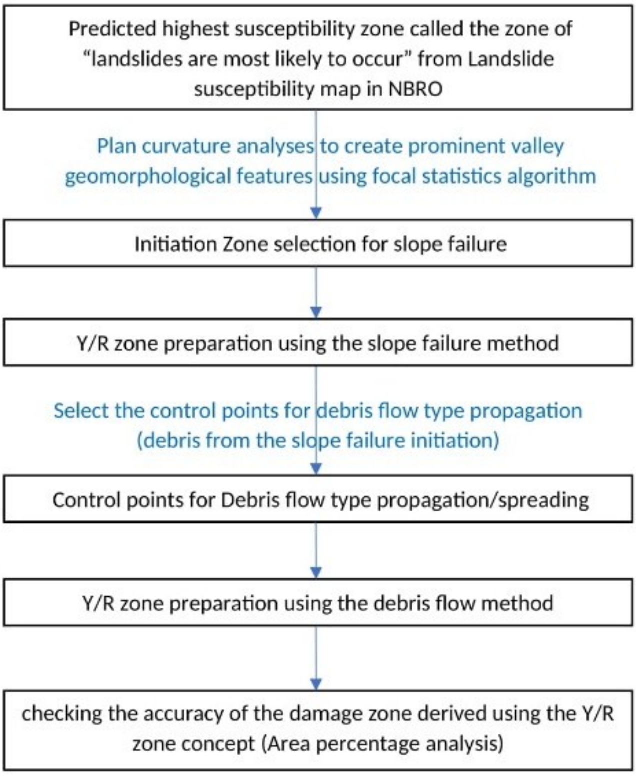


Figure 04: Flow diagram of the research methodology

4. Results and Discussions

The zone of "Landslides are most likely to occur" from the land susceptibility map produced by NBRO was sectioned based on morphology, and the selected sections were used to prepare the possible damage area using the slope failure method of the Y/R zone concept (Figure 5). This section was used as a guide to select the initiation area for the Aranayake landslide prior to the event. To select the appropriate sections, an already occurring landslide was considered, and two sections were used for the study. Prominent valleys and morphology for the analysis were obtained by the plan curvature analysis in ArcGIS using un disturbed light detection and ranging (LiDAR) terrain data of the terrain prior to the event.

However, the slope failure result by the Y/R zone methodology predicted the possible zone of initiation for the Aranayake following the colluvial deposit which has started from the rock outcrop of the mountain top. But the actual landslide hasn't yet been initiated from the rock outcrop boundary. With consideration of the pre-prediction, this result with the overestimation is acceptable. The result of the yellow zone and red zone from the slope failure method gave the most appropriate approach according to the existing morphology.

This analysis gave a result of the possible damage zone that led to the debris flow propagation/spreading over the downstream. The Y/R zones for debris flow types were used to demarcate the possible damage zone from the debris flow. When the huge mass spread over slopes following valleys is considered, the center of gravity of the mass in each cross-section within the valley morphology does not match with the line of the stream bed since the momentum of the mass. Therefore, the propagation line was drawn manually based on streamlines (produced by steepest path analysis) to the propagation line with the correcting streamlines by the knowledge of field verification and the smoothing technique of the cross-section analysis towards downstream.

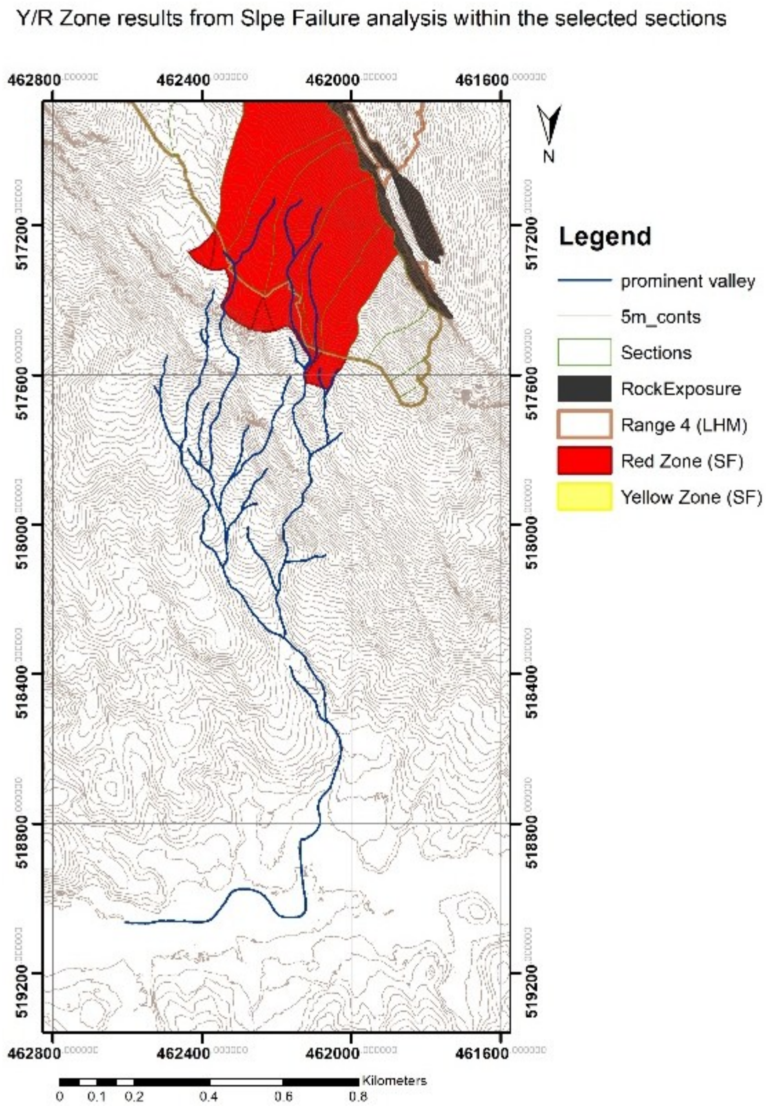


Figure 05: Y/R zone results of the selected section within "Landslides are most likely to occur"

Control points preparation for the debris flow propagation analysis was done by the high elevation propagation line and the end boundary of the yellow zone red zone results of slope failure method that was in higher elevation to the houses and human settlement within the area.

The Y/R zones were prepared using the debris flow method from the control points along the identified propagation line.

Both slope failure and debris flow results from Y/R zones were overlayed over the actual landslide boundary to obtain total predicted damage zones. The intersection was considered to calculate how much area has been covered by the Y/R zone method (Figure 6).

The results from Figure 6 show that the underestimated zones (middle of the flow path) compared to the actual landslide boundary, which is a result of the event occurring in three steps, each step modifying the terrain. In the first failure, the debris produced by slope failure was spread following the original morphology of the area. But, for each and every event except the first event, the morphology is modified by the debris flow event.

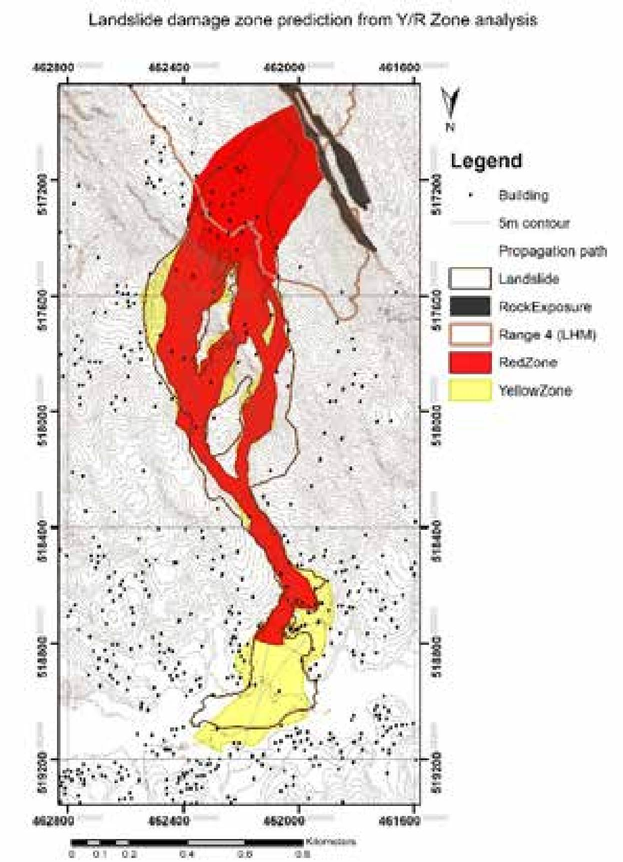


Figure 06: Damage zone prediction from yellow zone Red Zone analysis

Then the next event follows the modified morphology. The morphology changes in each event cannot be approached by the general Y/R concept for the failures of more than one event. Therefore, the underestimation can be expected to occur as the result in Figure 6.

5. Conclusions

According to the findings, the damage zone assessment based on the Y/R zone concept projected 77.89% as true-positive from the landslide's actual boundary.

The combination of slope failure and debris flow methods of Y/R zone can be considered as a successfully application when it comes to Aranayake micro catchment area and its' LHZM to predict the possible damage zones for the pre disaster arrangements.

However, the results highly depend on the resolution of the terrain and the scale of the investigation. For this study, LIDAR data is recommended for this better approach.

Field verification with an expert is highly recommended before making decisions.

Using this methodology for identifying potential failure locations, the damage zone assessment can be done with disaster management practices as an extension of this study for further studies. Also, this result can be directly used for landslide mitigation, evacuation practices, and the community-based disaster management plans in the Aranayake micro-catchment.

6. Acknowledgments

We would like to acknowledge Eng. (Dr.) Asiri Karunawardena, Director General, National Building Research Organisation for offering the opportunity of the research symposium.

7. References

1. Climate of Sri Lanka. (2019, June 20). Department of Meteorology, Sri Lanka.
2. http://www.meteo.gov.lk/index.php?option=com_cconten&view=article&id=94&Itemid=310&lang=ee&lang=en
3. Jayathissa, H.A.G. (2012). Definition classification and theoretical background of landslide and slope stability analyses, Lecture notes, M.Sc. In Engineering.
4. LHMP Annual Report (2017), Landslide Hazard Mapping in Sri Lanka, *Landslide Hazard Mapping Project,* 10-35.
5. NBRO User Manual (1995), Landslide Hazard Mapping in Sri Lanka, *Landslide Hazard Mapping Project SRL89/001*, 44-85.
6. Varnes, D.J. (1984). Landslide hazard zonation: a review of principle and practice, United Nations Educational Scientific and Cultural Organization, Paris.

Review and Validation of Slope Failure Hazard Zonation Method in Sri Lanka

T Wada[1], HH Hemasinghe[2], PMGR Bandara[2] and MDSS Karunarathna[2]

[1]Earth System Science Corporation Limited. Tokyo, Japan,
[2]Natinoal Building Research Organisation, Sri Lanka

Abstract:

Risk evaluation and hazard zoning are the basis of disaster risk reduction. Landslide Hazard Zonation Maps (LHZM) are developed by National Building Research Organisation (NBRO) in the Central mountainous Region in Sri Lanka. The hazard zones are determined by total scores of geology, slope, hydrology and drainage, land use and landform. In addition, NBRO is developing hazard maps consisting of "Yellow zones" (warning areas) and "Red zones" (restricted and control areas) based on the Landslide Hazard Zonation Maps. To support the hazard mapping, an automated program generating "Yellow and Red" zones was developed. The scoring system of the Landslide Hazard Zonation Maps and the algorithm of "Yellow and Red" zone maps were reviewed and validated by using actual disaster data.

The scoring system properly evaluate the landslide hazards. However, the "Modest level of landslide hazard exist" zone is too wide compared with the actual disaster records. Therefore, it is proposed to increase the threshold. The "Yellow and Red" zones were substantially calculated by the automated program. However, some manual corrections are required to finalize the "Yellow and Red" map in flat areas and scattered areas due to limitation of DEM accuracy. The flow paths of sediments are able to be considered using combination method of slope failure and debris flow "Yellow and Red" algorithms. On the other hand, actual initiation areas of slope failure are underestimated on the "Yellow and Red" method. Therefore, it is recommended to expand the initiation areas of slope failure "Yellow and Red" zones considering the scores of the Landslide Hazard Zonation Maps.

Keywords:* *Slope failure, Hazard zoning, Yellow (warning) and red (restricted and control) zones

1. Introduction

1.1. Background

Land use regulations and development controls are the important non-structural countermeasures for landslide risk reduction. The land use regulations inhibit increase of population and assets in landslide hazard areas and lower the risks of disasters. To achieve effective landslide risk reduction, proper risk evaluation and hazard zoning are required since the land use regulations are defined depending on the landslide hazard zonation.

National Building Research Organisation (NBRO) develops the Landslide Hazard Zonation Map (LHZM) in the central mountainous Region in Sri Lanka (Landslide Hazard Mapping Project, 1995). The LHZMs are the basis of landslide risk reduction in Sri Lanka (Bandara, 2018). Moreover, NBRO is working on further activities to designate "Yellow zones" (warning areas) and "Red zones" (restricted and control areas) through the international technical cooperation project with Japan International Cooperation Agency, "Project for Capacity Strengthening on Development of Non-structural Measures for Landslide Risk Reduction in Sri Lanka" ("Project - SABO"). The "Yellow" and "Red" zones are determined by considering topographical features of the hazard areas and the distribution of hazard areas in LHZM.

1.2. Landslide Hazard Zonation Map (LHZM)

The LHZM (Fig.1) are susceptibility maps of landslides. The creation method of the LHZM was developed by the Landslide Hazard Mapping Project (1995). NBRO continues preparing the LHZM in the whole landslide prone region. Landslide hazards are evaluated by six factors: geology, surface deposits, slope, hydrology and drainage, land use and landform, and classified into four categories: "Landslide not likely to occur", "Modest level of landslide hazard exist", "Landslides are to be expected" and "Landslides most likely to occur". In addition, several types of zones, such as past landslide affected/ damaged areas, are shown in the LHZM.

A challenge of the LHZM is the modest level or higher hazard areas are too wide. Ca. 70 - 80% of the total area is modest level or higher in the study area of Rathnapura and Kalutara. The other challenge is that flow paths of debris flows and collapsed soil of slope failures are not considered in the LHZM, which indicates only probability of initiation areas of disasters.

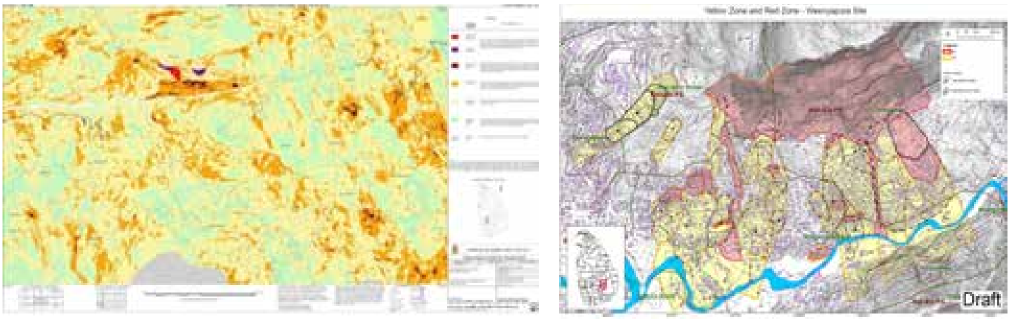


Figure 01: Landslide Hazard Zonation Map (LHZM) and Yellow and red zone map (hazard map)

1.3. "Yellow zones" (warning areas) and "Red zones" (restricted and control areas)

Based on the hazard evaluation, working group 1 (WG1) of the Project - SABO proposed new hazard zoning: "Yellow zones" as warning areas and "Red zones" as development restricted and control areas, (Y/R zones, Fig. 1). Similar Y/R system is utilized in Japan for development control and early warning (Kunitomo, 2003). Target disasters of the hazard maps of Y/R are slide, slope failure and debris flow (Fig.2). The criteria of Y/R for the three types of the disasters are proposed by the WG1 of the Project - SABO (Yang, 2021).

Objectives of this study are review of the LHZM and Y/R using actual disaster records and validation of automated slope failure Y/R calculation.

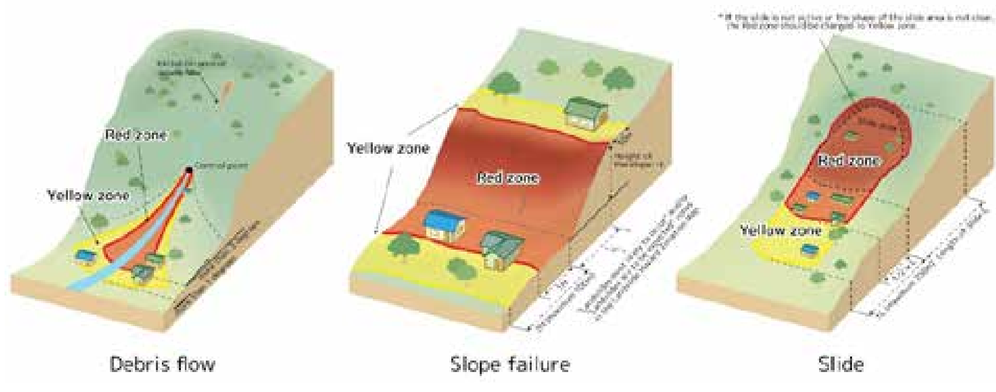


Figure 02: Criteria of the yellow and red zones

2. Study areas and method of analysis

2.1 Study areas and data

Study areas are initiation and affected areas of past slope failures in Ratnapura, Kalutara and Kegalle Districts. The potential and actual initiation/affected areas of slope failures were plotted on the map by field survey and/or detected by satellite images. 11, 19 and 5 sites data in Ratnapura, Kalutara and Kegalle were utilized for the analysis.

LHZMs and Y/R hazard maps which were calculated based on LHZM by using automated algorithm were also utilized on the analysis (Fig. 3). SRTM and LiDAR Digital Elevation Model (DEM) were utilized on the Y/R calculation.

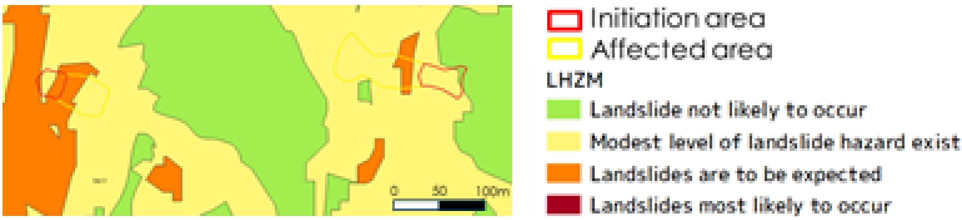


Figure 03: Initiation/affected areas of slope failures and LHZM

2.2. Method

The criteria of the classes of LHZM is shown in Table 1. The scores of LHZM were compared with the actual slope failures to validate and calibrate the classification of LHZM.

Table 01: Ranges of factors for LHZM

Classes of hazard zones	Ranges of total scores (geology, surface deposits, slope, hydrology and drainage, land use and landform)	Colors
Landslide not likely to occur	Score <= 40	Green
Modest level of landslide hazard exist	40 < Score <= 55	Yellow
Landslides are to be expected	55 < Score <= 70	Amber
Landslides most likely to occur	70 < Score <=100	Brown

Algorithm of slope failure Y/R proposed by WG1 of the Project-SABO is shown in Fig.4. The "Landslides are to be expected" (amber) or higher (brown) zones in the LHZMs were assumed as potential initiation areas of slope failures. Height of the potential initiation areas of slope failures (H) were calculated using DEM. "Red" zones were designated for the potential initiation areas as well as lower slopes within 1 H from the edges of initiation area. In addition, "Yellow" areas were generated in the lower slopes within 1 H from the edges of "Red" area. These Y/R areas are assumed as affected areas by collapsed soil. Additional 10m "Yellow" areas were designated in the upper slope of the potential initiation areas as collapsed zone of scarps. These calculations were automated. Results of the Y/R calculation were overlaid to the actual slope failures and validated.

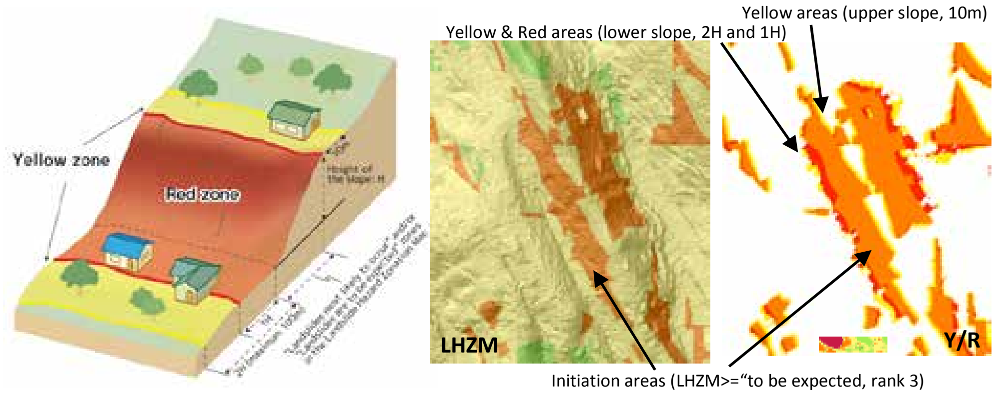


Figure 4: Slope failure Y/R calculation/generation based on LHZM

3. Results and discussions

3.1. Comparison between LHZM and potential/actual slope failures

More than 90% of the potential/actual slope failures which plotted/surveyed by this study are located in the "Modest level of landslide hazard exist" or higher zone in LHZM (Fig. 5). However, ca. 70 - 80% of the total area are originally designated as the "Modest level of landslide hazard exist" or higher zone in LHZM. Thus, it is ideal to reduce the hazard zone in the LHZM without decreasing the detection ratio of the slope failures.

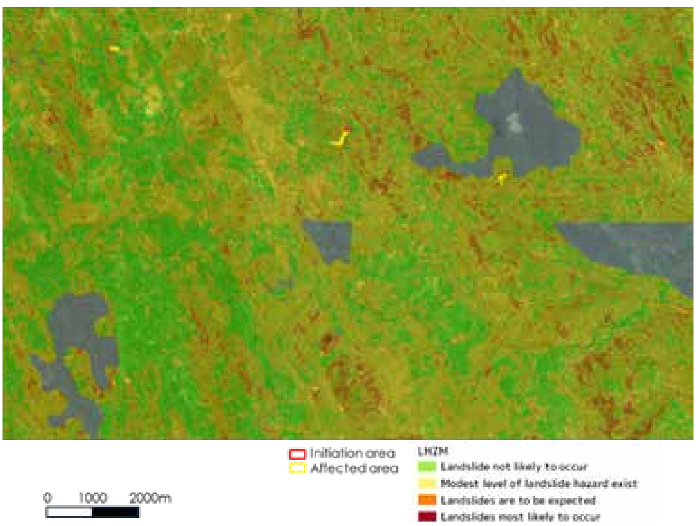


Figure 05: Comparison between LHZM and potential/actual slope failures

Figure 6 shows a histogram of LHZM final score in the actual initiation/affected areas and no slope failure areas in the study area of Ratnapura and Kalutara. In general, the final scores of LHZM tend to be high in the initiation/affected areas of slope failures. It suggests that the scoring system works properly. The ratio of initiation areas especially increase in case that final scores of LHZM exceed 55, which is a threshold of the "Landslides are to be expected" area. Therefore, the threshold seems to be significant. On the other hand, there is no large difference on frequency of initiation/affected areas at the threshold (40) for "Modest level of landslide hazard exist". The affected area ratio increase at 48 of the final score. Thus, it is proposed to reduce areas of "Modest level of landslide hazard exist" by shifting the threshold from 40 to 48.

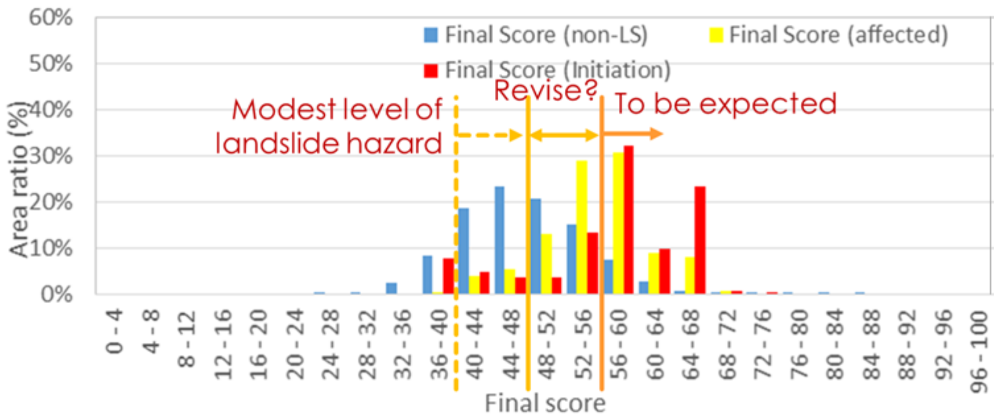


Figure 06: Histogram of LHZM final score in the initiation/affected areas and no slope failure areas

Figure 7 shows an example of revised LHZM in the Ratnapura site by shifting the threshold for "Modest level of landslide hazard exist". The "Modest level of landslide hazard exist" or higher hazard areas are reduced less than 40%, but most of the actual initiation areas are still located in the hazard areas. On the other hand, downstream ends of the actual affected areas tend to be outside of the hazard area due to long travel distance of sediment transportation by debris flows. Hence, it is recommended to combine the method of debris flow Y/R into the LHZM to reflect the flow paths on the hazard maps.

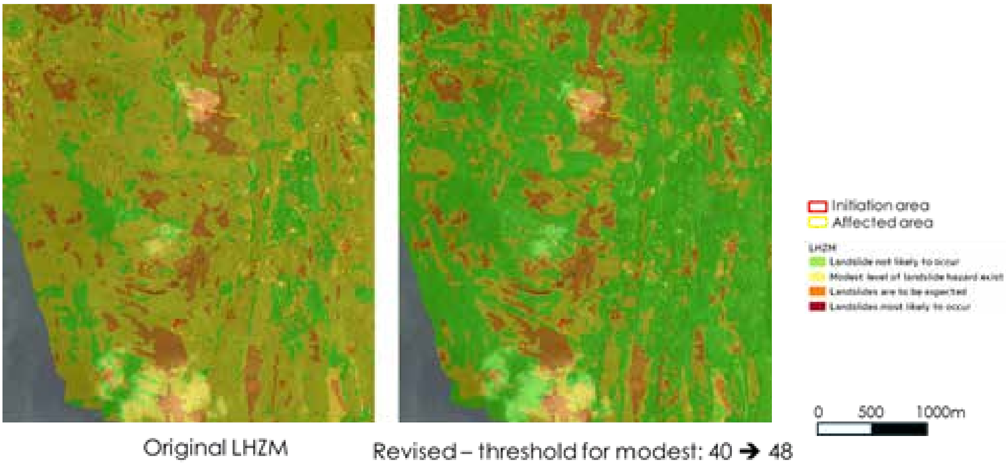


Figure 07: Comparison between original and revised hazard level classification on LHZM

3.2. Automated generation of slope failure Y/R

Figure 8 shows examples of Y/R for slope failures generated by the automated process using DEM and LHZM. The Y/R zones which are determined by the height and location of the initiation slope ("to be expected" areas of LHZM) are substantially calculated. However, scattered and isolated meshes of Y/R remain even though those meshes are brushed up by spatial filter. Additionally, few downstream ends of the Y/R located in flat areas are not correct due to the limitation of accuracy of DEM. These points need to be corrected by manual operation.

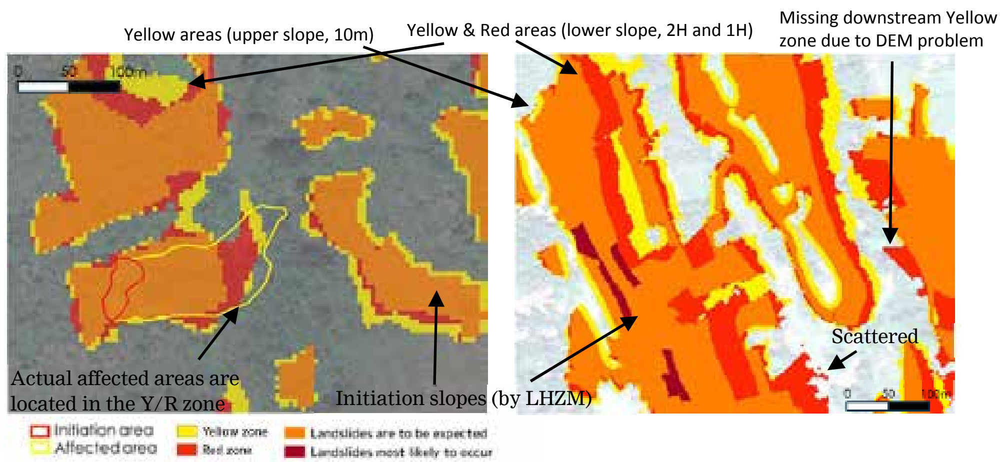


Figure 08: Generated Y/R based on LHZM and DEM

3.3 .Validation of slope failure Y/ R

Around half of the actual initiation areas of the slope failures in the study sites were located outside of the "to be expected" or higher hazard areas in the LHZM (Fig. 9, left). As a result, Y/R zones are underestimated compared with the actual initiation/affected areas. It indicates necessity of expansion of initiation slopes for Y/R generation. It is proposed to utilize areas having 48 scores or higher in the LHZM as initiation slopes of Y/R, in order to expand the Y/R zones and cover actual slope failures. To determine the proper initiation slopes of Y/R, further data collection and study are necessary.

Fig. 8 (left) and 9 (right) are the good examples; actual initiation areas are located in the "to be expected" areas of the LHZM, and generated Y/R areas cover the actual affected areas. The downstream end of the actual affected area becomes debris flow and flow to the outside of slope failure Y/R. Therefore, this area is covered by the debris flow Y/R.

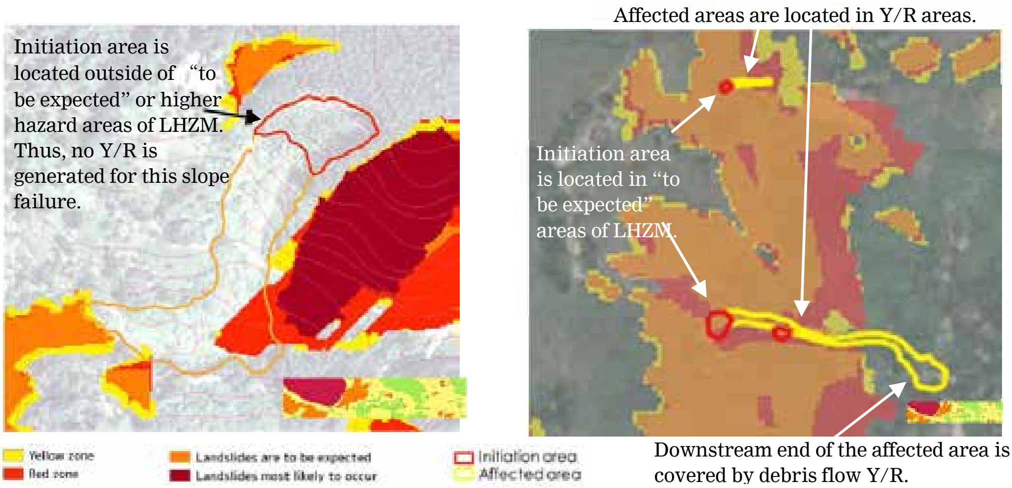


Figure 09: Slope failure Y/R, LHZM and actual initial/affected areas

4. Conclusion

National Building Research Organisation (NBRO) develops landslide hazard zonation map (LHZM) in Sri Lanka. The hazard zones in LHZM are determined by total scores of geology, slope, hydrology and drainage, land use and landform. The scoring system works properly to evaluate the landslide hazards. However, the "Modest level of landslide hazard exist" zone is too wide compared with actual disaster records. Therefore, it is proposed to shift the threshold of the "Modest level of landslide hazard exist" in the scoring system from 40 to 48 to shrink the "Modest level of landslide hazard exist".

A challenge of the LHZM is that flow paths of debris flows and collapsed soil of slope failures are not considered. Hence, NBRO is developing hazard maps consisting of "Yellow zones" (warning areas) and "Red zones" (restricted and control areas) based on the LHZM through the international technical cooperation project with Japan International Cooperation Agency. An automated program was developed to generate "Y/R" zones using LHZM and DEM. The Y/R zones were substantially calculated by the automated program. However, some manual corrections are necessary to finalize the Y/R map in flat areas and scattered areas due to limitation of DEM accuracy.

The flow paths of sediments are able to be considered using combination method of slope failure Y/R and debris flow Y/R algorithms. On the other hand, initiation areas of slope failure are underestimated on the Y/R method. Therefore, it is recommended to utilize areas having 48 score or higher in the LHZM as initiation areas of slope failure Y/R maps.

The LHZM and Y/R hazard maps are the key data for disaster risk reduction through early warning as well as land use regulations and development control. Therefore, improvement of risk evaluation and hazard zoning is important for future. Continuous data collection and further studies to determine high hazard slopes is required.

5. References

1. Bandara, R. M. S., Jayasingha, P. (2018). Landslide Disaster Risk Reduction Strategies and Present Achievements in Sri Lanka. *Geosciences Research, Vol. 3, No. 3,* 21-27, https://dx.doi.org/10.22606/gr.2018.33001
2. Landslide Hazard mapping Project (1995). LANDSLIDE HAZARD MAPPING IN SRI LANKA. NBRO, pp.286
3. Kunitomo,. M. (2003). Application and Advantages of Hazard Maps for Sabo in Japan. *International Training Program on Total Disaster Risk Management 10-13 June 2003,* 85-90
4. Yang, P., Nishikawa, T., Hemasinghe, H. H., and Jayathissa, H. A. G. (2001). Inventory Survey of Slope Failures in Sri Lanka. *Multi-Hazard Early Warning and Disaster Risks,* 363-374, https://doi.org/10.1007/978-3-030-73003-1

Importance of Tallying Inherent Factors on Numerical Evaluation of Landslide Hazard Zonation Methodology: A Case study on Dumbara Landslide, ayagama

TMKB Ekanayake[1], PD Jayarathna[1], YL Yatawara[1], WMAD Wanasundara[1]

[1]Scientist, National Building Research Organisation, Sri Lanka

Abstract

Landslides associated with extreme weather conditions during monsoon seasons are the most pressing natural disasters frequently affecting the life, property and economy in Ratnapura District. It is essential to understand the affecting factors in landslides, to minimize or eliminate such damages due to landslides. National Building Research Organisation (NBRO) introduced a numerical evaluation system and prepared a landslide hazard Zonation maps in Sri Lanka (NBRO, 1995).

According to the NBRO, the numerical evaluation system considers only about six major factors know as terrain factors. Apart from these terrain factors, understanding the additional inherent factors that act upon the initiation of the landslide is vitally important. In this study, deadly "Dumbara landslide" in Ayagama Divisional secretary area, Sri Lanka was used as a case study to identify additional inherent factors such as pegmatite intrusion through the joint plane, breaking slope, regional discontinuities in the bed rock, etc. This study concludes that the inherent factors add an additional weightage on numerical evaluation system. Also this methodology will be developed as a frame work for the other landslides occurred in Ratnapura District.

1. Introduction

The geographical setting of Sri Lanka is characterized on Asia–Pacific Region, which is considered as one of the most natural hazardous zones in the World (Cooray, 1994). As a tropical country, Sri Lanka experiences two major monsoonal weather patterns dominated by South–West and North–East. Most of the natural disasters that occur in Sri Lanka are followed by these two rainfall periods. In recent past years, landslides were the predominant and catastrophic natural disaster that occurred in Sri Lanka (Patley, 2012). The global spatial distribution of fatal landslides is heterogeneous and Sri Lanka is considered as one of the locations with clusters of fatal landslides (Petley, 2012). It has seriously affected the economic growth of the country and interrupted social development in all urban, suburban and rural area communities.

Out of 25 administrative Districts in Sri Lanka, tweleve (12) areas are recognized as landslide-prone areas, and they are namely, Badulla, Bibile, Nuwara - Eliya, Rathnapura, Kegalle, Kandy, Matale, Kalutara, Galle, Matara, Kurunegala and Hambantota. These landslide-prone areas are positioned within Central Highlands and the surrounding slopes covering around one-third of the total land area of the Island.

The major two causative factors which directly influence the initiation of the landslides in Sri Lanka are terrain conditions and triggering events. Slope angle, improper land-use, un planned constructions, and geological settings are the important terrain conditions and the main triggering event is intensive rainfall during monsoonal seasons.

National Building Research Organisation (NBRO) introduced a numerical evaluation system for landslide hazard zonation of Sri Lanka based on the studies carried out using landslide investigations done in Badulla and Nuwara-Eliya Districts (NBRO,1995). The methodology developed based on the above research introduced six major factors known as terrain factors namely; bedrock geology, hydrology and drainage, surface overburden, slope angle range, land use and landforms. In the landslide hazard level evaluation process these factors have different effects in the initiation of a landslide. However, in addition to these terrain factors understanding the inherent factors that act upon the initiation of the landslide is vitally important.

In recent past years, Sri Lanka experienced several major landslides. The landslides in Koslanda, Meeriyabadda, Aranayaka and Dumbara are a few of them. Among them, the "Dumbara Landslide" which occurred on 4th of June 2021 in Ayagama District Secretarial Division in Ratnapura District caused extensive damage and took two human lives. This study is mainly focused on the "Dumbara Landslide" as a case study.

This case study aims to examine potential of modifying the Numerical Evaluation System by introducing some inherent factors that might initiate this landslide.

2. Study Area

Due to its hilly geomorphology and active rainy seasons, Ratnapura is considered as one of the landslide-prone Districts of the Island. The large-scale catastrophic landslide that occurred in Dumbara claiming 2 lives on 04th June 2021 was examined for the study. This rapid-onset disaster was triggered by high intense rainfall and it buried a portion of the Madapola road and destroyed a house. The landslide took place on the escarpment slope facing east.

Ayagama is a Region situated in the low Country wet zone of the country. The area receives rains during the South West monsoon from May to September and during inter-monsoon from October to November. The dry season prevails from March to December. Even though the Island is located outside of a cyclone belt, it experiences extreme rainfall events due to the cyclones activated in the Indian Ocean. During the first week of June 2021, a low-pressure condition caused heavy rains around this area. The result was several large-scale landslides in Ratnapura and Kaluthara Districts and floods along the Kalu River.

Figure 01: Location and access

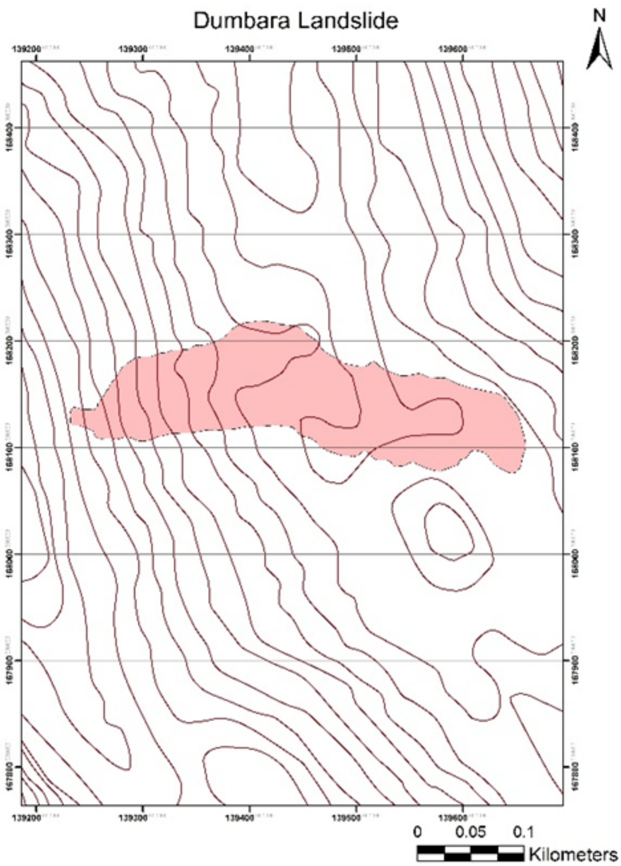


Figure 02: Map of the Dumbara landslide

The Dumbara landslide and the adjacent landslide have initiated in the upper slope of the escarpment slope, facing east, in the morning at 0600 hrs approximately. According to villagers, the landslides occurred with a sound of a large blast. Then the Dumbara landslide moved downward and with the rainy conditions developing into a debris flow. A temporary debris dam was developed by these transported debris as their movement was stopped across the Dumbara stream. The adjacent landslide was stopped on the Madapola road.

Figure 03: Drone image of the landslides

The scale of the disaster was massive. The length of the debris flow is about 400 m long. The main scarp is about 18 m long and 8 m deep (Figure 03).

Figure 04: Main scarp of the Dumbara landslide

3. Methodology

The methodology for the study comprised two steps: (1) fieldwork (2) analysis Initially, the data related to the terrain factors were gathered and then the inherent factors were identified. The numerical evaluation of the landslide hazard was done by following the numerical evaluation system introduced to the landslide hazard zonation mapping in Sri Lanka (NBRO, 1995). Then the landslide hazard zone was accessed. Scoring was done according to the predefined factor classes

4. Results And Discussion

Table 01: Numerical Evaluation for the slope

Terrain Factor		Factor Class	Linguistic Rating & Score
Bedrock geology and geological structures	Lithology	Khondalite	Medium - 3
	dip & type of slope	Scarp 46^0-55^0	Medium - 2
	Deviation angle	Angle 121^0-155^0	Low - 2
	Other discontinuities- better elaborate (joints- intensity must be included)	Very high	Very High - 2
Type of natural soil cover and thickness		Residual >8m	High - 9
Slope range & category		Slope Category II (35^0)	High - 16
Hydrology and drainage	Surface drain condition	Poorly drained	Very High - 6
	Proximity to streams/valleys/water bodies	Distance>41m	Low - 1
	Groundwater flow	Two Groundwater springs	Very High - 6
	Upper slope length up to the catchment boundary	Length>101m	Very High - 5
Land use and management		JR	Medium - 8
Landform		Complex mountain slope	High - 5

According to the numerical evaluation, the large-scale slope where the Dumbara landslide occurred has accumulated 65 points. According to the NBRO decision making criteria, it concludes that the slope can be categorized as the "Landslides are to be expected" area. This area is categorized as the "Landslides are to be expected" zone in the 1:10000 Landslide Hazard Zonation Map as well.

The large-scale slope can be categorize in to three different area.

1. The area where the large-scale Dumbara landslide was occurred
2. The area where the second landslide was occurred (Adjacent landslide)
3. Stable slope in between the landslides

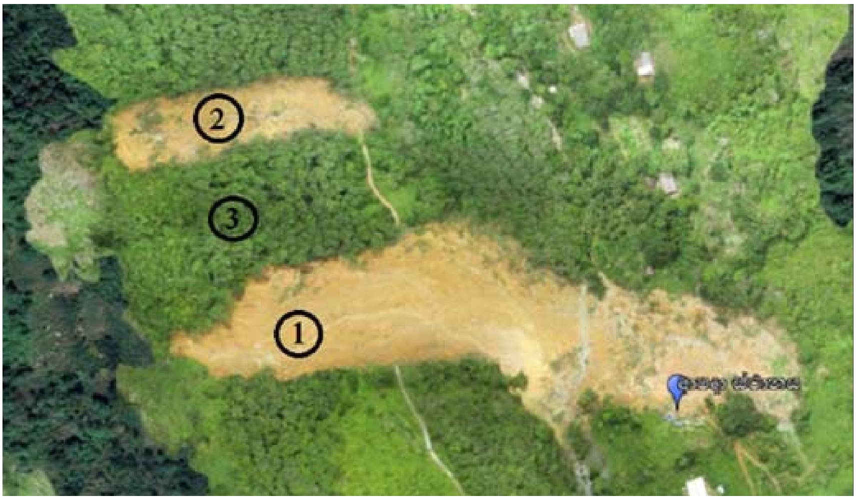


Figure 05: Three different study areas

Occurrence of the Dumbara landslide and the adjacent landslide suggests that this slope should yield a much higher score in the numerical evaluation. This general rating of 65 points represent the general terrain conditions of this large-scale slope. The reasons for the deficit of points can be justified by identifying the inherent factors for the initiation area of the each landslide. The inherent factors for the each area can be listed as followed.

Table 02: Terrain factors for each area

Inherent factors for the Dumbara landslide	Factors common for the Dumbara landslide and the stable slope	Factors common for the Dumbara landslide, stable slope and the adjacent landslide	Factors common for the stable slope and the adjacent landslide	Inherent factors for the adjacent landslide
Pegmatite intrusion	Underlying Khondalite Bedrock	Slope angle of 35^0	Rubber estate	Large scale boulders on debris
Cleared land on upper slope	Graphite traces on bedrock	Deviation angle of 135^0		
Regional lineation intersecting the slope		Residual soil cover of 9m		
Feldspar rich joint planes		Road-cut on breaking slope		
Shallow water table on mid slope				

The pegmatite intrusion along a joint plane has resulted in a higher percentage of completely weathered feldspar in the immediate soil layers which led to planes concentrated with clay. Fractional amounts of graphite were also identified in the area. Both these factors act as a favorable condition to creating a slip surface.

Figure 06: Clay rich bedrock

Also, it was identified that the immediate portion of the land on the upper slope was lately cleared. This led to more infiltration under heavy rains.

Figure 07: Cleared land above the main scarp

Further analysis shows that the initiation area of the landslide overlaps with an intersection of a Regional lineation and the slope direction. Usually, a Regional lineation

Figure 08: Distribution of lineations

remarks a weak zone of the bedrock. Also, the slope is on a limb of the Dumbara synform. This indicates that the underlying zone is a Fault/ Fracture zone.

All the inherent factors identified at the initiation area of the Dumbara landslide are favorable factors for a landslide to initiate. They acted as the causative factors for the

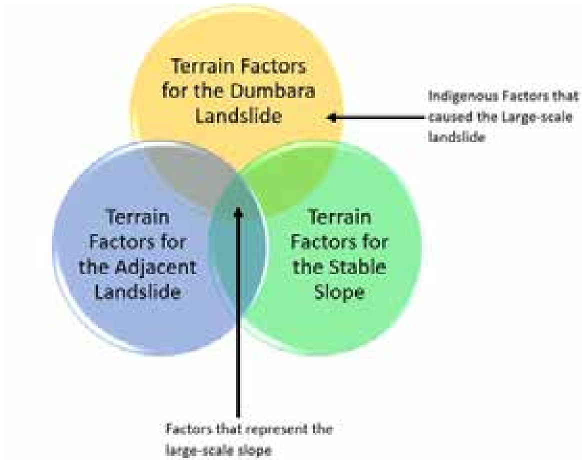


Figure 09: Graphical representation of terrain factors

Dumbara landslide occur at that certain position on the large-scale slope. This shows that the additional points that required to identify the area as a "Landslides most likely to occur", are represented by these inherent factors.

5. Conclusion

Even though the numerical evaluation suggests that the slope where the Dumbara landslide was occurred rates as a "Landslides are to be expected" zone, occurrence of the landslide demonstrate that the initiation area should yield more points. This study conclude that the deficit of these points represents by the inherent factors. They drive the hazard zonation in to "Landslides most likely to occur" zone. Hence, identifying the inherent factors and tallying them on the numerical evaluation can be used to locate a more susceptible zone for a landslide to occur, on a large-scale slope.

References

1. Petley, D., 2012. Global patterns of loss of life from landslides. Geological Society of America, 1130-1133.
2. Froude, M.J., Petley, D.N., 2018. Global fatal landslide occurrence from 2004 to 2016. National hazard and earth system sciences, 2161-2181
3. User manual on landslide hazard zonation mapping; NBRO (1995), National Building Research Organisation, Colombo.
4. Varnes, D. J. 1978. Slope movement types and processes. In: Special Report 176: Landslides: Analysis and Control (Eds: Schuster, R. L. & Krizek, R. J.). Transportation and Road Research Board, National Academy of Science, Washington D. C., 11-33.
5. Hutchinson, J. N. 1988. General Report: Morphological and geotechnical parameters of landslides in relation to geology and hydrogeology. Proceedings, Fifth International Symposium on Landslides (Ed: Bonnard, C.), 1, 3-35. Rotterdam: Balkema.
6. Cooray, P.G., 1994. The Precambrian of Sri Lanka: a historical review. Precambrian Research, 66, 3-18.

Influence of Chemical Fertilizer on Triggering Shallow Landslides in Tea Fields: a Case Study from Galaboda Tea Estate

KGDS Wijesiri[1], DAG Madusanka[1], WMAD Wanasundara[1], RMIU Rathnayake[1],

[1]Scientist, National Building Research Organisation, Sri Lanka

Abstract

Ratnapura is identified as a critical District for landslide, slope failure and rock fall hazards due to the severity of inherent terrain factors and it is enhanced by the intense rainfall. Initiations of Landslides in tea fields were observed significantly in recent disastrous period. Hence it is vitally important to finding the causative factors, chemical fertilizing is one of the key processes that can change the structure of the soil. Therefore, this study was conducted to identify the relationship between the fertilization and the occurrence of landslides with regards to a case study recorded in Galaboda tea estate of Galkandura Division in Ratnapura Divisional Secretary, Sri Lanka.

The study area was divided into two locations as fertilized field as tea cultivated land and non-fertilized field as nearby forest land, while terrain & triggering factors are constant such as rainfall, slope, and soil type. Soil samples from the above two locations were collected to test the fertilizer concentration and the shear strength using ICP-MS test and Direct Shear test respectively. Influence of fertilization for the initiations of the landslides will be identified by analyzing the test results.

Keywords: Fertilization, Shear strength, ICP-MS test, Direct shear test

1. Introduction

Landslides are the natural disasters that are frequently occurred in Sri Lanka. Badulla, Nuwara-Eliya, Ratnapura, Kegalle, Kandy and Matale Districts which are located in the central hills and Kalutara, Matara, Galle and Hambanthota Districts in the Southern hills are identified as the landslide-prone areas in Sri Lanka. Among those, approximately 20,000 km^2 (30.7%) of the land area is highly susceptible to landslides (Hemasinghe et al, 2017). With the increasing demand for the development and expansion of human settlements, landslides have become a major concern in the mountainous Regions of the Country.

With the beginning of shifting village farming communities of the Country, people started cropping around Central hills with the introduction of export crop plantations such as; rubber, tea, cocoa, pepper & cinnamon. This contributed to the distribution of population and their livelihood in Central Highlands and as a result, hazards began to occur in these lands (Paul and Abraham, 2017).

The nature of agricultural activities in Sri Lanka has changed over the centuries based on availability of arable land and water resources. Natural resources are depleting as a result of rapid population increase, and this is reflected in the availability of land for construction (Natural Resources of Sri Lanka, 1991). The majority of the cultivated land was being converted into construction sites in this situation. In the case of doing cultivation process in large scale within limited suitable lands, the chemical fertilizers, mostly NPK fertilizers (Nitrogen, Phosphorus, and Potassium) were widely used to achieve a good harvest from the targeted Crop. As a result of that, chemical concentration in the soil have reached to the relatively higher levels. When we apply the chemical fertilizer in field it increases the crop production and also alters the soil properties. This chemical mixed soil will behave differently from the natural soil. So, it became necessary to study on the nature of this chemical mixed soil and how it affects the geotechnical properties of soil such as physical and engineering properties of soil (Paul and Abraham, 2017). Ikutegbere, (1996) and Amobi, (1998) has shown that NPK fertilizers reduce both the cohesion and angle of internal friction of the soil (Ezeokonkwo, 2011). In recent past years, several shallow landslides have occurred in tea cultivated lands in Sri Lanka. Nivithigala - Wanniyawaththa (26 deaths), Kalawana - Wewalkandura (13 deaths), Eheliyagoda - Arabbadakanda (12 deaths), Pinnawala, Galabada Junction, Hapugoda and Egoda walebada some of them. There is a less consideration for doing research works to identify the relationship between occurrence of landslides and the usage of fertilizer in cultivation lands.

Figure 01: Landslide occurred in a Tea land (Pinnawala).

2. Objectives

The main objective of this case study is to identify the fertilization impact on initiation of landslides using chemical and physical analyses between fertilized and non-fertilized fields while terrain & triggering factors are constant.

3. Study Area

The study area is situated in the Southern part of the Central Highlands of Sri Lanka and the area is becoming highly populated due to urbanization. However, the growth of population, which forced to settlements towards the higher slopes and inappropriate land-use practice had a major influence to increase the frequency of landslides in this particular area. During the past two decades, this area experienced several devastating landslides.

This case study is focusing in Galkandura Division in Galaboda Tea Estate in Ratnapura District, Sabaragamuwa Province. It has a $(25^0 - 30^0)$ slope angle with uniform slope facing to South-East direction and it consists of clayey SAND soil. The area of interest is located around 6.716429°N latitude and 80.468582°E longitude.

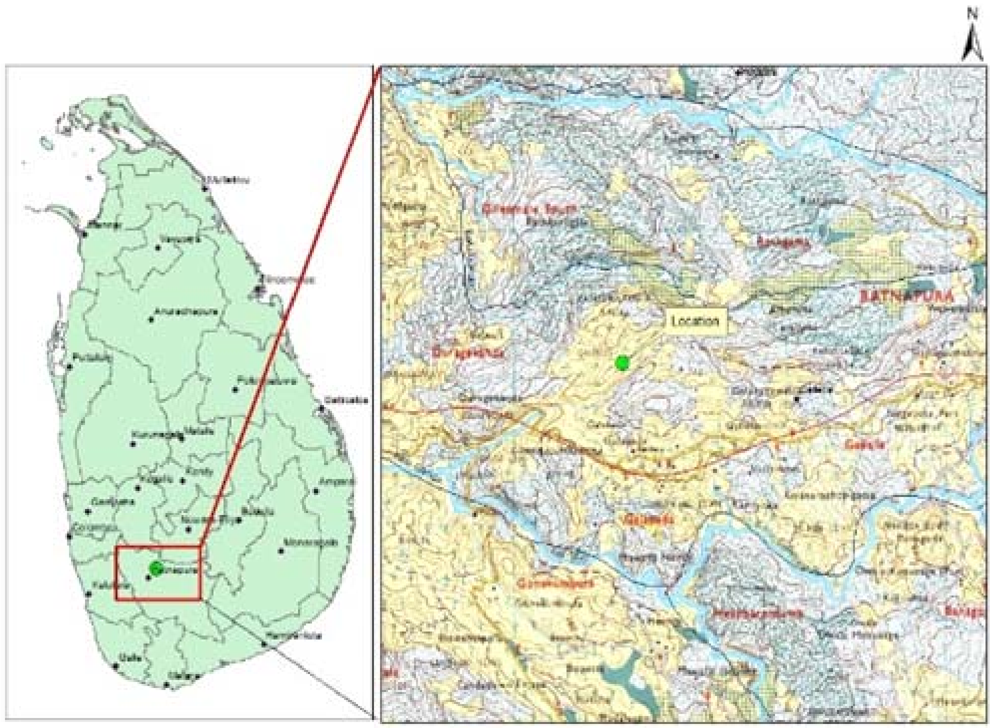


Figure 02: Location of the study area

The study area was divided into two locations as fertilized fields as tea cultivated land and Non-fertilized fields as nearby forest land, while terrain & triggering factors are constant such as rainfall, slope, soil type, rock type and structural features.

Figure 03: Google Earth image of the study area

The fertilized tea land consists of a tea cultivation which is monitoring by Galaboda tea estate. That tea land is fertilized by the tea estate after every 45 days. The current tea plantation has commenced in 2017 and since then the estate management has used two types of fertilizer types as T-750 and U-709 which containing Nitrogen, Phosphorus, and Potassium with respective ratios. Estate management has used T-750 in the year 2017 and after the year 2018 they have used U709. As the tea estate mentioned the forest part has not fertilized in the recent past.

Figure 04: Actual image of the fertilized and non-fertilized fields mentioned in the study area

4. Methodology

In this study different types of analysis were done separately to both fertilized and non-fertilizes fields by collecting soil samples from each field separately. Soil samples were collected from two fields and the testing was done separately.

4.1. Direct Shear Test

Two un disturbed soil box samples were taken from each fertilized and non-fertilized land. The undisturbed samples were experimented in the laboratory to find the shear strength (C and Φ value) of each sample separately.

Figure 05: while taking undisturbed sample

4.2. Mackintosh Test

Separate tests were done in the field to identify the variation of soil strata with depth in both lands. Here hammer blow count to penetrate 0.30 m of each location were taken continuously until hammer bouncing.

4.3. ICP-MS Test

Soil samples were collected from each fertilized and non-fertilized land at 20 cm intervals to 1 m depth starting from the surface. All cations available in the soil samples and their concentrations were calculated using this test. 0.1 g of each representative sample was used for digestion.

Figure 06: solution preparation for ICP-MS test

4.4. Sieve Analysis

Sieve Analyses were done for both field samples to identify the Particle size distribution patterns following BS 1377 : 1990 (Part 2 & Part 7).

The following results were interpreted using the concentration values obtained by the ICP-MS test according to the depth values which having 20 cm intervals from the surface in both fertilized and non-fertilized fields separately.

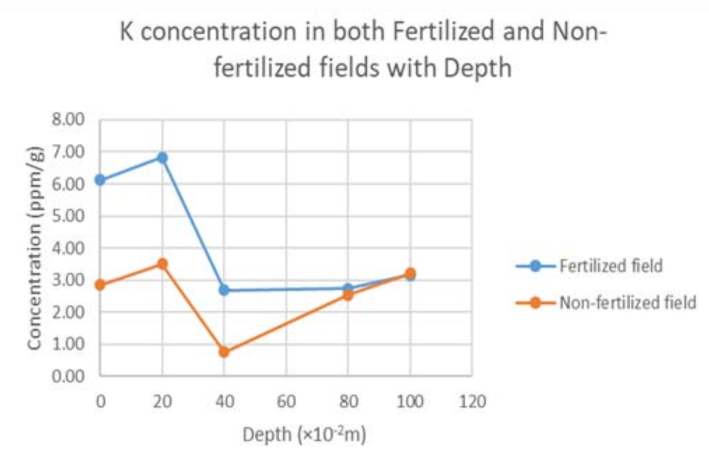


Figure 07: Potassium concentration in both fertilized and non-fertilized fields with Depth

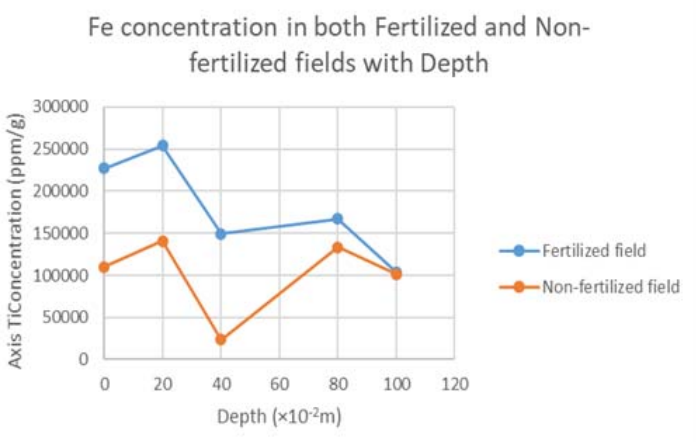


Figure 08: Iron concentration in both fertilized and non-fertilized fields with Depth

5. Results

Table 01: Concentration of K, Al, Ca and Fe per unit weight with Depth from the surface in both Fertilized and Non-fertilizes land.

Depth	K (ppm/g)		Al (ppb/g)		Ca (ppm/g)		Fe (ppm/g)	
(×10-2m)	S 01	S 02	S 01	S 02	S 01	S 02	S 01	S 02
0	6.129723	2.847725	342466.2	136592.3	7.296938	6.228746	227120.6	110055.5
20	6.832206	3.508141	373153.4	166053.4	8.039525	4.576459	254189.1	140589.7
40	2.683598	0.767523	194002.6	40478.62	5.783507	1.74074	149203.4	23548.75
80	2.734896	2.540874	150968.7	134090.1	5.981748	4.351907	166917.7	133187.7
100	3.156615	3.219603	211536.7	163513.9	5.1785	2.662064	103851.4	101476.2

Note: S 01- Fertilized land, S 02- Non-fertilized land

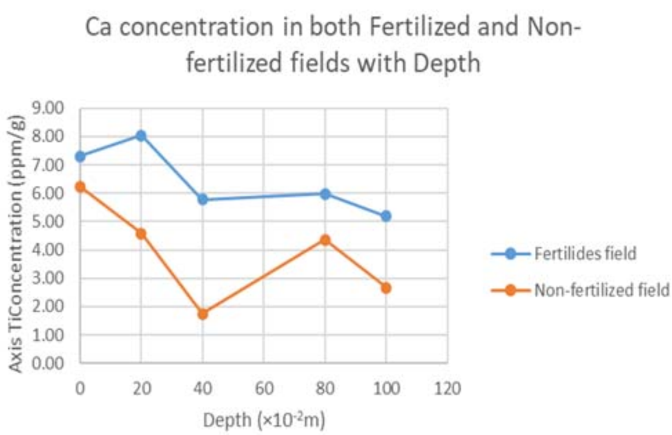


Figure 09: Calcium concentration in both fertilized and non-fertilized fields with Depth

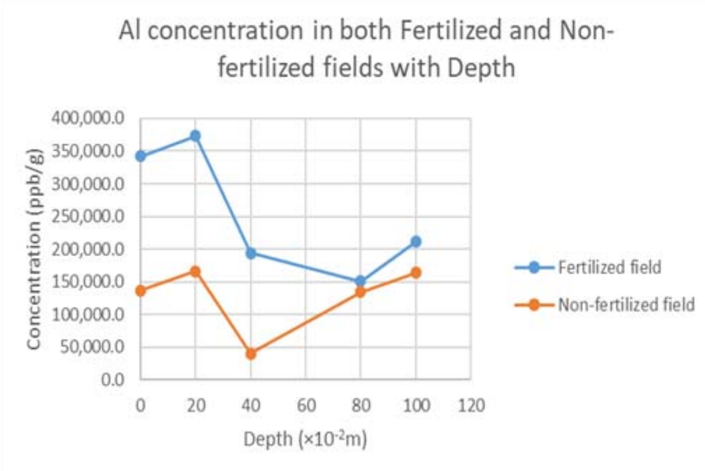
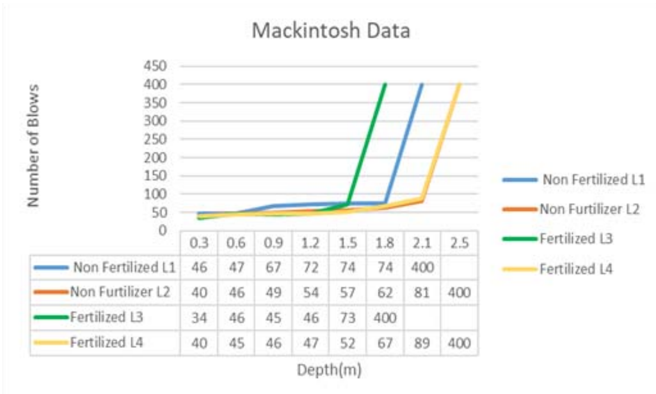


Figure 10: Aluminum concentration in both fertilized and non-fertilized fields with Depth

The Mackintosh penetration test was done in four separate locations choosing two locations from each fertilized and non-fertilized field.



	0.3	0.6	0.9	1.2	1.5	1.8	2.1	2.5
Non Fertilized L1	46	47	67	72	74	74	400	
Non Furtilizer L2	40	46	49	54	57	62	81	400
Fertilized L3	34	46	45	46	73	400		
Fertilized L4	40	45	46	47	52	67	89	400

Figure 11: Mackintosh test results for each location

Two undisturbed soil samples were taken from both fertilized and non-fertilized field and those samples were tested to obtain the cohesion of the material (C) and the friction angle of the material (φ).

Table 02: cohesion of the material (C) and the friction angle of the material (φ) and unit Weight of soil in both fields.

Values	Fertilized field	Non-fertilized field
Cohesion (C)	9 KPa	16 KPa
Friction Angle (φ)	37^0	40^0
Unit Weight	$14.380kNm^{-3}$	$15.296\ kNm^{-3}$

Using the above obtained C and φ results, an analysis was done to find Factor of safety (FOS) values using the Geo Studio Software.

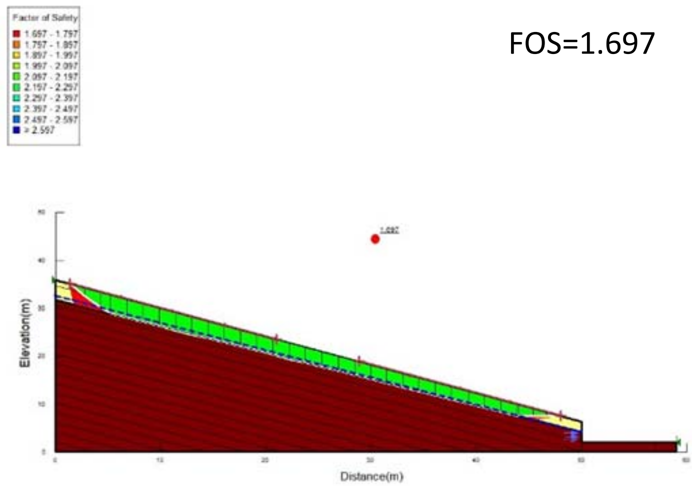


Figure 12: Geo slope analysis for the Fertilized field

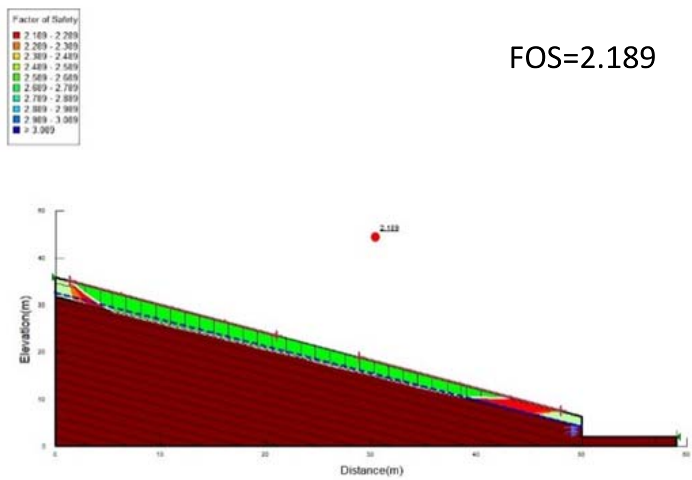


Figure 13: Geo slope analysis for the Non-fertilized field

Particle size distribution was done for both fertilized and non-fertilized field to identify the differences and similarities of particle sizes in both lands.

Table 03: Percentage passing with sieve sizes in both lands (Sample1 -Non-fertilized, Sample2 -Fertilized)

Sieve Size (mm)	Percentage Passing (%)	
	Sample1	Sample2
50.00	-	-
37.50	-	-
25.00	-	-
20.00	100.00	100.00
9.50	77.83	67.89
6.30	72.01	55.06
4.75	70.26	51.15
2.00	58.60	36.96
1.18	50.75	31.11
0.60	44.60	27.47
0.425	41.87	25.84
0.30	37.95	23.17
0.212	34.82	20.92
0.15	31.87	18.67
0.063	28.85	15.86

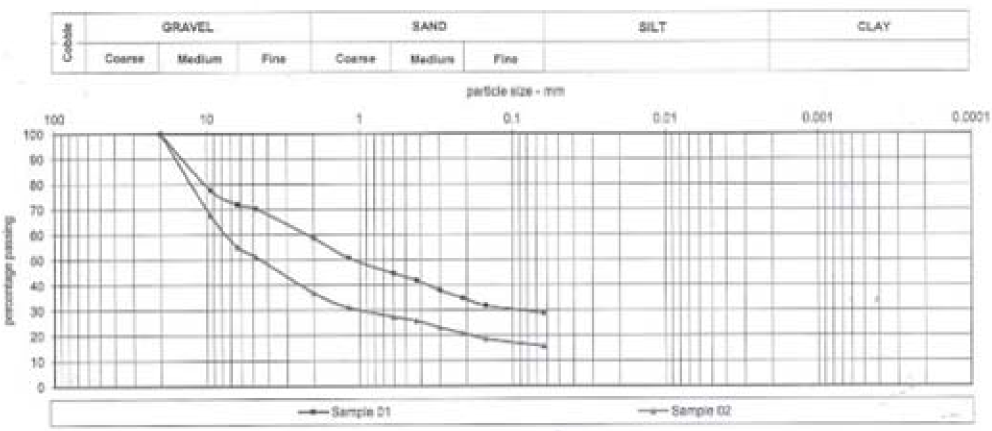


Figure 14: Particle size distribution curve in both lands (Sample1 -Non-fertilized, Sample2 -Fertilized)

Final results were taken by analyzing the above particle size distribution curve.

Table 04: Gravel, Sand and Silt & Clay percentages in both lands

Field	Depth (x10 -2m)	Gravel (%)	Sand (%)	Silt & Clay (%)
Fertilized	50-80	63	21	16
Non-fertilized	50-80	41	30	29

There is a Decision-making criterion which use to determine potential of landslide susceptibility developed by National Building Research Organization and the following results were acquired using that criteria (Dulanjali et al, 2018).

Table 05: Relative weighting for major factors, sub factors and factor classes based on the NBRO model (NBRO User Manual, 1995) for both fertilized and non-fertilized fields

Major Factor	**Sub Factor**	**Factor Classes and scores for Fertilized land**	**Factor Class and score for Non-Fertilized land**
Bedrock geology and geological structures	Lithology	Charnockitic Biotite Gneiss, [5]	Charnockitic Biotite Gneiss, [5]
	Amount of dip & type of slope	Dip 25⁰-30⁰, [2]	Dip 25⁰-30⁰, [2]
	Deviation angle	Angle 0⁰-10⁰, [6]	Angle 0⁰-10⁰, [6]
	Other discontinuities	Very high, [2]	Very high, [2]
Type of natural soil cover and thickness	Soil cover	Residual 2m-8m, [8]	Residual 2m-8m, [8]
Slope range & category	Slope range and category	Slope Category III, [13]	Slope Category III, [13]
Hydrology and drainage	Surface drain condition	Moderately drained, [4]	Moderately drained, [4]
	Proximity to streams/valleys/water bodies	Distance>10m, [2]	Distance>10m, [2]
	Groundwater flow	Seepage, [8]	Seepage, [8]
Land use and management	**Land use and management**	**Well managed tea(JT1), [3]**	**Degraded Forest(W2), [8]**
Landform	Landform	Straight(F51), [5]	StraightF51, [5]
Total score out of Hundred		**58**	**63**

6. Discussion

Resulted graphs for concentrations of K, Al, Ca, and Fe show a considerable high in the fertilized field than the non-fertilized field. And also, according to the above results chemical concentration has mostly gathered into near surface and it is said that the fertilizer which used for cropped generally used to concentrate in to near surface. Phosphorous and Nitrogen were unable to detect by ICP-MS method due to their anionic behavior.

Estate Management has used T-750 and U-709 (NPK fertilizer) for the tea field and it mainly contains Nitrogen, Phosphorous and Potassium in respective ratios. ICP-MS test can be done only for cations and as a consequence of this Nitrogen and Phosphorous concentration has not calculated in this test. For further studies Nitrogen and Phosphorous concentration also can be calculated using chemical titration test, Scale Invariant Feature Transform (SIFT) method (Sumiharto et al; 2020) or Features from Accelerated Segment Test (FAST) method (Sumiharto et al; 2020).

Mackintosh test was done to identify the soil strata in both lands. Resulted graph for mackintosh test results shows that there is no huge variance in both lands and it reflects that there are unique soil layers in both fields.

When concerning the Direct Shear test results, there is a significant decrease of cohesion, internal friction angle and unit weight in fertilized soil samples than Non - fertilized soil samples.

With the results of particle size distribution test, the gravel percentage in fertilized field is greater than in the Non-fertilized land. And Silt & Clay percentage in fertilized field is less than in the Non-fertilized land. Both soil samples from two locations were taken from the same elevation in the same slope. Consequently, we assume that the rock layers which have coursed to form the overburden soil in both lands is similar. Further chemical analysis should be done to identify the relationship of forming gravel particles when adding fertilizer to the soil.

When considering the scores obtained in the Decision-making criteria there is a higher percentage of possibility to occur a landslide in a fertilized land than in a non-fertilized land.

7. Conclusions

Addition of fertilizer to soil affects the cohesion, internal friction and unit weight of soil material as revealed by test results. Consequently, shear strength of soil reduces with application of fertilizer. According to the above test results obtained from limited soil samples, Factor of Safety value for slope stability of fertilized soil has been decreased by 22.48% than non-fertilized soil. Reduction of resisting forces of slope stability results an increase of landslide vulnerability within a specific terrain. These results were taken from analyses with limited number of samples and resources. This outcome should be further affirmed by conducting this experiment with more samples and locations in different tea fields.

8. Reference

1. Dulanjali P.H.E., Jayathissa H.A.G., Indrathilake, H.M.L., 2018. Determination of site specific landslide susceptibility potential based on decision making criteria. *NBRO International symposium,* Volume 8, pp. 35-41.
2. Ezeokonkwo J.C., 2011. Engineering Properties of NPK Fertilizer Modified Soil. *Journal of Emerging Trends in Engineering and Applied Sciences, (JETEAS)* 2 (6): 962-966
3. Hemasinghe H., Rangali R.S.S., Deshapriya N.L., and Samarakoon L., Landslide susceptibility mapping using logistic regression model (a case study in Badulla District, Sri Lanka). *7th International Conference on Building Resilience; Using scientific knowledge to inform policy and practice in disaster risk reduction,* ICBR2017, 27 – 29
4. Sumiharto R., Putra R.G. and Demetouw S., 2020, June. Methods for Determining Nitrogen, Phosphorus, and Potassium (NPK) Nutrient Content Using Scale-Invariant Feature Transform (SIFT). *In 2020 8th International Conference on Information and Communication Technology, (ICoICT)* (pp. 1-4).
5. Sumiharto R., Putra R.G. and Demetouw S., 2020. Methods for Determining Nitrogen, Phosphorus, and Potassium (NPK) Nutrient Content Using Features from Accelerated Segment Test (FAST). *International Journal of Computer Science and Software Engineering, 9* (1), pp.1-5.
6. Varsha C Paul, Jiss K Abraham, 2017. Effect of Fertilizers on Soil Strength. *International Research Journal of Engineering and Technology (IRJET)*, 04(05), pp. 2307-2311.

IOT and LoRa Based Landslide Early Warning System for Rural Areas

TR Bentharaarachchi[1], DS Munasinghe[2]

[1]Information Technologist, National Building Research Organisation, Sri Lanka
[2]Senior Scientist, National Building Research Organisation, Sri Lanka

Abstract

Landslide is a natural phenomenon, and mostly the high-intensity rainfall triggers it. Therefore, most early warning systems monitor real-time rainfall as an indicator of a landslide. In addition, several types of ground movement detectors are used to estimate ground deformation on identified landslide areas. National Building Research Organisation (NBRO) also monitors the real-time rainfall pattern by using more than 300 automated rain gauge networks installed in the country's Central Highlands to facilitate landslide early warning.

The installation of automated rain gauges incurs a high cost for installing and monitoring the equipment. NBRO is spending a considerable sum of money to maintain the rain gauge network as to facilitate an effective early warning system bacause, early warning dissemination plays such a significant role in disaster management. However, the rural communities do not seem to receive effective early warning messages due to technological barriers and communication gaps.

This research has identified several gaps in the automatic rain gauge network and early warning mechanisms, such as the high cost of the automated rain gauge and poor communication between the early warning centres and the communities. The research is focused on making two-way communication between vulnerable houses and the early warning centres to make a more effective early warning system in the country. The methodology includes the installation of Arduino sensors? modules? and the LoRaWAN network to share the information between vulnerable committees and the respective agencies.

Keywords: Early warning system, Node MCU, LoRa, LoRaWAN

1. Introduction

The National Building Research Organisation was established in 1984 to assist construction activities in the Country. However, later, in 1989, NBRO reached a milestone becoming the national focal point for landslide risk management in the Country. Under that, NBRO initiated the landslide hazard zonation mapping programme in Badulla and Nuwara-Eliya Districts. According to the landslide mapping programme, 2/ 3 of the country is prone to landslide hazards, and it is considered as the most severe hazard in the country (Zubair et.al, 2006). According to the Disaster Management Act number 13 of 2005, landslide is a major hazard event in the country. Considering the recent history, , Meeriyabedda landslide in 2014 and Aranayake landslide in 2016 taught different lessons to NBRO officers to reconsider the landslide early warning system.

The definition of landslide is the movement of unstable soil mass to a downslope area with all its associated ground features such as buildings, trees etc (Highland, et.al, 2008). Sri Lanka has mainly rain-induced landslide hazards and every year, landslides occur during the rainfall season in the Country. According to the disaster register, landslide can occur in the months of May and November as usually Sri Lanka receives heavy rainfalls during the SW monsoon and NE monsoon periods, aligning with the above pattern. In addition to that, haphazard construction activities also can trigger a landslide event through out the year. According to the risk profile development project, NBRO identified that about 100,000 buildings are located in the areas having highest landslide probability , and of which, nearly 15,000 buildings have been identified in areas where landslide symptoms are already visible.

These areas having visible landslide symptoms require close monitoring. Geologists use various methods and instruments to identify landslide risk areas, such as; bore holes, inclinometers, ground extensometers, soil moisture meters & etc (Dunnicliff, 1982). Main disadvantage of these methods is the very high cost incur for the equipment. If they can replace them with low-cost equipment, the number of units installed in the field can be increased to get an accurate outcome.

Mostly the boreholes, inclinometers, ground extensometers, soil moisture meters store data locally and the stakeholders have to visit the local sites and acquire the data for analysis. Sometimes, sensors are placed on high-risk areas and the data collectors have to risk their lives to collect the data. During heavy rains, data collectors should collect and analyze the data as soon as possible for issuing the warnings for the people who live in such high-risk areas. The early warning efficiency will increase if the data reach the central location on real-time.

The rain gauges are commonly used to monitor the rainfall level to issue the landslide early warning messages. During the rains, the water infiltrated to the ground and increases the porewater pressure, which is the causative factor for creating a landslide. Therefore, it is an essential requirement to monitor the soil water behavior and define the threshold limits for given area to issue the landslide early warnings. Therefore, real-time data capturing equipment plays a significant role to understand the risk levels.

The technology is updating frequently, and there are new microcontrollers i.e. Arduino mini, micro, Nano, Uno, Mega etc. (products compare, 2021). All of these units need an external Wi-Fi module for connecting with a network or internet. In this case, a new product is introduced with inbuilt Wi-Fi, named as Node MCU, and it has been considered as a suitable technology for landslide early warning application development.

1 Node MCU

Node MCU (Figure 01) (Arduino on ESP8266, n.d.) is an open source IOT (Internet of Things) (Internet_of_things, n.d.) platform integrated with ESP 8266 (WiFi Module - ESP8266, 2021) (Figure 03) low cost Wi-Fi based microchip with full TCP/ IP stack and microcontroller capability (NodeMCU DEVKIT, 2021). The Node MCU was invented after ESP 8266 chip was invented by Espressif Systems in 2013 (Esp8266, 2021). Pin configuration of Node MCU and ESP 8266 are shown from Figure 02 to 04.

Figure 01: Node MCU (source: Google Images)

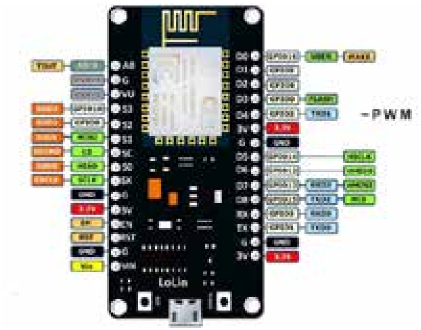


Figure 02: Pin Configuration (source: Google)

Figure 03: ESP 8266 (source: Google Images)

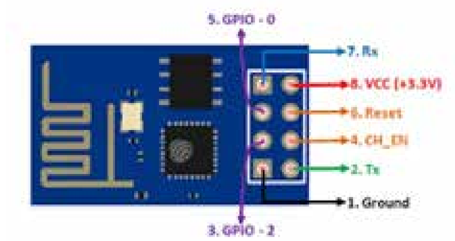


Figure 04: Pin Configuration (source: Google Images)

The Node MCU will act as a single data collector in the field. Increasing more Node MCUs and then configuring them to send data frequently will help identify an activated landslide before it occurs. While using Node MCUs it has to face some limitations. Node MCU must be connected through a wireless network and it means that there is a need for a powerful AP (Access Point) to connect with Node MCU. The disadvantage is reducing the AP coverage area in the hillside due to obstacles such as trees and other objects. In order to overcome this limitation, LoRa technology will be the best answer.

2 LoRa & LoRaWAN

LoRa (Long Range) (What Is LoRa, 2021) (Fig. 2.1) is a low power wireless data communication system that supports a long-range connection (Figure 05). It uses a radio frequency modulation technique that is generated by SMTECH LoRa Transceiver chip. LoRa uses frequency bands like 433MHz in Asian countries, 868 MHz in European countries and 915 MHz in North America. In 2018, SMTECH announced new LoRa chipset with reduced power consumption and increased transmission range. Now, LoRa have a coverage area more than 5 Km in rural areas.

Figure 05: LoRa Module (source: Google Images)

Figure 06: LoRaWAN (source: Google Images)

When using a LoRa module, it has advantages as well as dis advantages (LoRa | Advantages of LoRaWAN | Disadvantages of LoRaWAN). Low cost, long coverage, and low power consumption are the advantages, and un suitability for high-data rate transmission, inability to transmit frequently, and difficulty to use on highly populated networks are the disadvantages of LoRa.

The LoRa modules can be used as P2P (Point to Point) or Networked points. When using point-to-point communication, two LoRa modules communicate through RF (Radio Frequency). If it is used as a networked point, it needs a gateway to communicate with it. Then it needs LoRaWAN (Figure 06). LoRaWAN is also a low power wide area network based LoRa chip (What is LoRaWAN® Specification, 2021). That gateway is connected to a network via a standard IP connection. Gateway simply converts the RF packets to IP packets and vice versa.

2. Reviewed Methodology

All sensors within less than 5 Km can be connected through this LoRaWAN (Silva, 2016). In 9th NBRO Annual Symposium, the author introduced a low-cost Arduino basic extensometer and rain gauge (Bentharaarachchi, 2018). In that case, extensometers can also be connected through it and also, rain gauges (Jayawickrama, 2016). Also tilt sensors, underground water pressure sensors and ground resistivity sensors also can be attached to this system as shown by Figure 07.

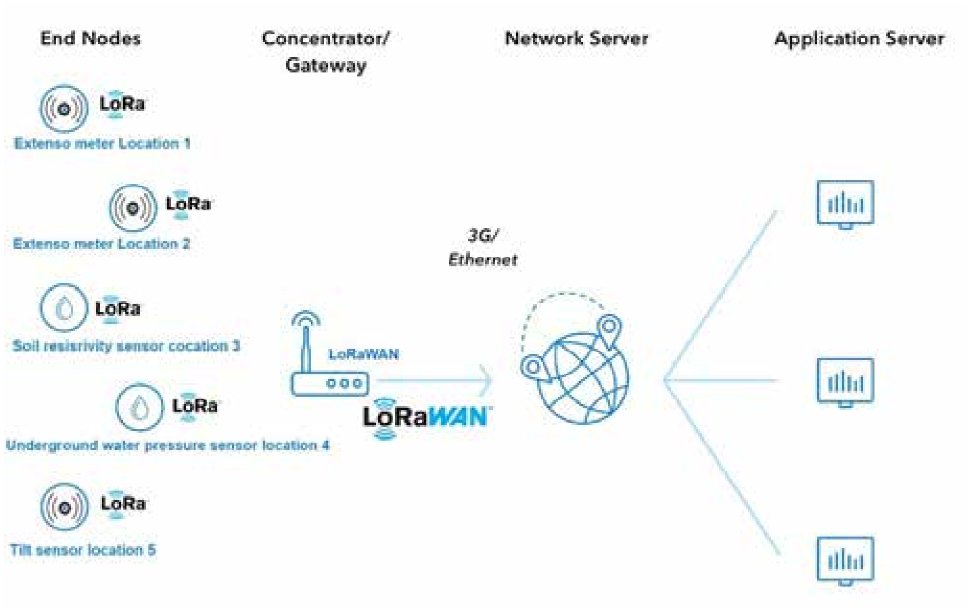


Figure 07: Sensors connects with LoRaWAN

Each node must have a LoRa module, then the sensor values can be shared through the network. Each LoRa ceates a range less than 5 Km. All LoRa modules are connected with LoRaWAN. LoRaWAN should be configured with a web server through a HSDPA Dongle or high-power AP. At regular time intervals, data will be sent by sensors through installed nodes to LoRaWAN and LoRaWAN uploads that data to the webserver. From the webserver, officers can collect and analyze the data.

In this method each node does not need an individual connection to the internet. That is a major advantage of this system. If the node connects with internet individually, it needs 3G/ 4G coverage to every node. In most rural areas the signal strength is very low. If the node is placed on a network blind-spot, it will not work at all. Also, the cost of each module will be high.

While using LoRa modules, it does not need a network coverage for all nodes. LoRaWAN only needs a network 3G/ 4G connection. LoRa modules create their own network, and they can be situated at any place. LoRa modules can be run through a 3000 - m A battery and a solar charger due to their low power consumption.

3. Conclusion

This experiment is based on Node MCU, LoRa and LoRaWAN modules. All the units must be configured and tested under present situation in the field and compared with present data received from the sensors. All the tests should be continued for a minimum of 6 months to get an accurate working condition of that network. The system should be first implemented and installed in a low-risk area as a trial for further modifications and error correction. Also, the system may fail due to environmental conditions in those rural areas. It is necessary to ascertain that a unit works and does not have any physical or factory fault, and that is why it must be run for about six months under the present data monitoring system. After proper inspection in these six months, the unit can be deployed for actual field operations.

4. Acknowledgement

Author wishes to thank Mr. B.V.P.Jayakody, Scientist, Mr. Clarence Perera, Consultant, Mr. Thusitha Jayawikrama, Consultant and also Ms. Malithi De Silva, Scientist, of National Building Research Organisation for the support given to conduct the research.

5. References

1. *Arduino on ESP8266*. (n.d.). Retrieved from https://github.com: https://github.com/esp8266/Arduino
2. Bentharaarachchi, T. (2018). Introducing Cost Effective Technology Using Real Time Data. *NBRO Symposium Proceedings* (p. 49). NBRO.
3. Esp8266. (2021). Retrieved from https://www.espressif.com/: *https://www.espressif.com/en/products/socs/esp8266*
4. Internet_of_things. (n.d.). Retrieved from https://en.wikipedia.org/: *https://en.wikipedia.org/wiki/Internet_of_things*
5. Jayawickrama, G. T. (2016). Real Time data acquisition in landslides, flow path identification. *NBRO Symposium Proceedings* (p. 79). NBRO.
6. JOHN DUNNICLIFF Geotechnical Instrumentation Consultant, Lexington, Massachusetts. (1982). *GEOTECHNICAL INSTRUMENTATION FOR MONITORING FIELD PERFORMANCE*. TRANSPORTATION RESEARCH BOARD NATIONAL RESEARCH COUNCIL ,WASHINGTON, D.C. .
7. Lareef Zubair and Vidhura Ralapanawe, Upamala Tennakoon,. (2006). *Natural Disaster Hotspots*. The World Bank.
8. LoRa | *Advantages of LoRaWAN* | *Disadvantages of LoRaWAN*. (n.d.). Retrieved from https://www.rfwireless-world.com: https://www.rfwireless-world.com/Terminology/Advantages-and-Disadvantages-of-Lora-or-LoRaWAN.html
9. Lynn M. Highland, United States Geological Survey, and Peter Bobrowsky, Geological Survey of Canada. (2008). *The Landslide Handbook - A Guide to Understanding Landslides*. U.S. Geological Survey Circular 1325.

10. *NodeMCU DEVKIT*. (2021). Retrieved from https://github.com: https://github.com/nodemcu/nodemcu-devkit-v1.0
11. *products compare*. (2021). Retrieved from https://www.arduino.cc/: https://www.arduino.cc/en/products.compare
12. Review on Wireless Transmission Methods in Landslide Early Warning Systems. (2016). NBRO *Symposium Proceedings* (p. 83). NBRO.
13. What Is LoRa. (2021). Retrieved from https://www.semtech.com: https://www.semtech.com/lora/what-is-lora
14. *What is LoRaWAN® Specification*. (2021). Retrieved from https://lora-alliance.org: https://lora-alliance.org/about-lorawan/
15. *WiFi Module - ESP8266*. (2021). Retrieved from https://www.sparkfun.com: https://www.sparkfun.com/products/17146